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**Kasai et al.**

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(54) **ELECTRO-OPTICAL DEVICE HAVING A STORAGE CAPACITOR FORMED BY A DATA LINE AND A POTENTIAL LINE**

(58) **Field of Classification Search**  
CPC ..... G09G 3/3291; G09G 3/3233; G09G 2310/0289; G09G 2310/0275;  
(Continued)

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(56) **References Cited**

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U.S. PATENT DOCUMENTS

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8,643,575 B2 \* 2/2014 Kim ..... G09G 3/3291  
345/82

2006/0107143 A1 5/2006 Kim et al.  
(Continued)

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FOREIGN PATENT DOCUMENTS

(21) Appl. No.: **17/025,253**

JP 2006-113548 A 4/2006  
JP 2009-211035 A 9/2009  
(Continued)

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OTHER PUBLICATIONS

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**Related U.S. Application Data**

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(63) Continuation of application No. 16/585,983, filed on Sep. 27, 2019, now Pat. No. 10,810,947, which is a  
(Continued)

(57) **ABSTRACT**

(30) **Foreign Application Priority Data**

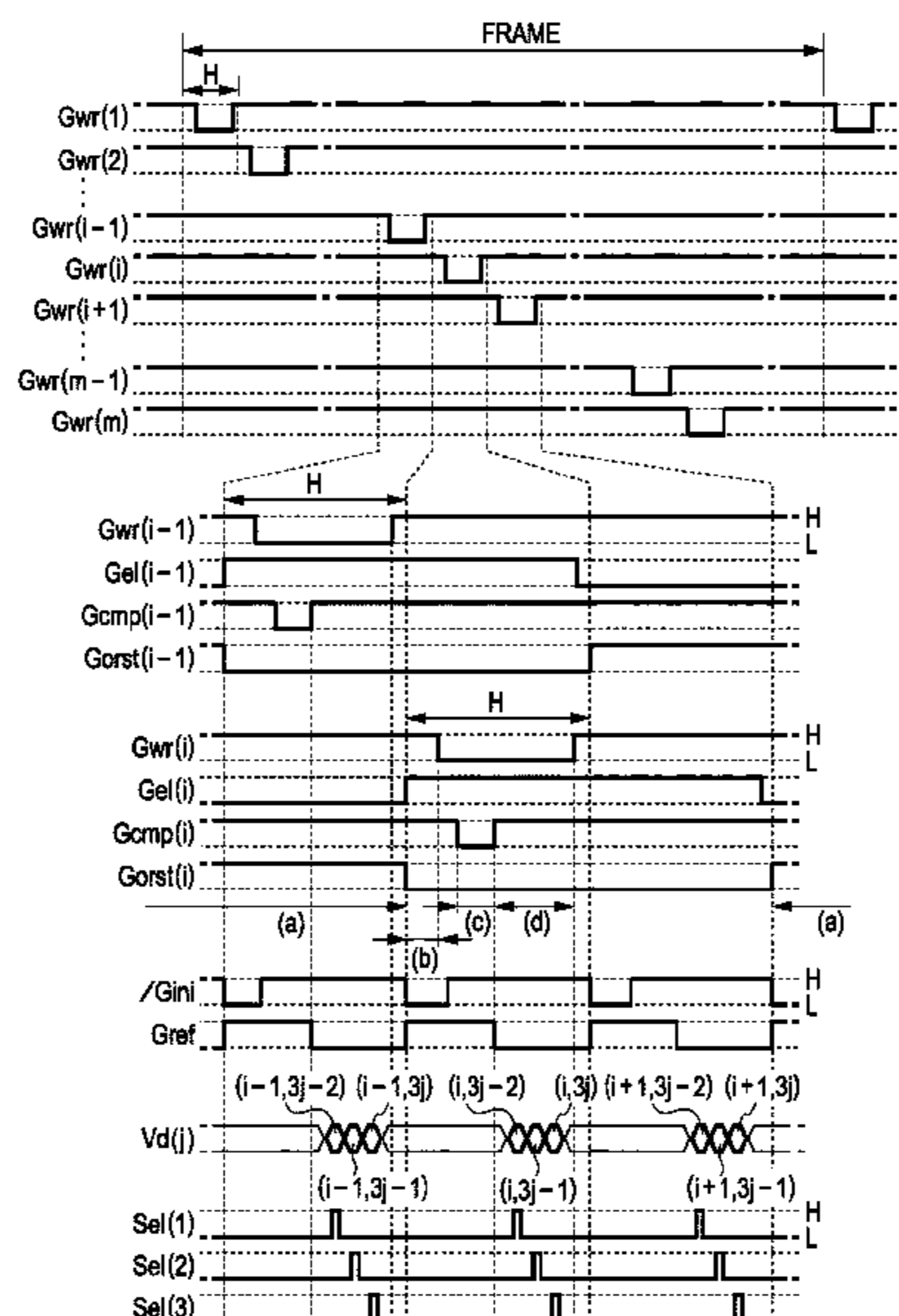
Nov. 16, 2011 (JP) ..... 2011-250386

An electro-optical device is provided with a plurality of data lines, a plurality of potential lines supplied with a predetermined potential, a driving transistor controlling a current level according to the voltage between the gate and the source, a first storage capacitor which holds the voltage between the gate and a source of the driving transistor, and a light-emitting element. One data line among the plurality of data lines and one potential line among the plurality of potential lines are arranged to be adjacent to each other, and a second storage capacitor holding the potential of the one data line is formed by the one data line and the one potential line.

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**G09G 3/3291** (2016.01)

(52) **U.S. Cl.**  
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(Continued)

**14 Claims, 20 Drawing Sheets**



**Related U.S. Application Data**

continuation of application No. 16/393,200, filed on Apr. 24, 2019, now Pat. No. 10,453,400, which is a continuation of application No. 15/959,765, filed on Apr. 23, 2018, now Pat. No. 10,311,800, which is a continuation of application No. 13/669,897, filed on Nov. 6, 2012, now Pat. No. 9,984,630.

(52) **U.S. Cl.**

CPC ..... *G09G 2300/0838* (2013.01); *G09G 2300/0861* (2013.01); *G09G 2300/0876* (2013.01); *G09G 2310/0256* (2013.01); *G09G 2310/0275* (2013.01); *G09G 2310/0289* (2013.01); *G09G 2310/0297* (2013.01); *G09G 2320/045* (2013.01)

(58) **Field of Classification Search**

CPC ... *G09G 2310/0256*; *G09G 2310/0297*; *G09G 2300/0838*; *G09G 2300/0814*; *G09G 2300/0861*; *G09G 2300/0876*; *G09G 2320/045*

See application file for complete search history.

(56)

**References Cited**

U.S. PATENT DOCUMENTS

2006/0139255 A1 6/2006 Kim et al.  
 2006/0208669 A1\* 9/2006 Huynh ..... H05B 45/48  
 315/312

2007/0262935 A1\* 11/2007 Shin ..... G11C 19/184  
 345/84  
 2008/0266330 A1\* 10/2008 Park ..... G09G 3/2003  
 345/690  
 2009/0135107 A1\* 5/2009 Kim ..... G09G 3/3241  
 345/76  
 2009/0195534 A1 8/2009 Kasai  
 2010/0039411 A1 2/2010 Yatabe et al.  
 2011/0050741 A1\* 3/2011 Jeong ..... G09G 3/3291  
 345/690  
 2011/0175881 A1\* 7/2011 Kim ..... G09G 3/3291  
 345/211  
 2012/0105501 A1\* 5/2012 Nakamura ..... G09G 3/3233  
 345/690  
 2013/0093737 A1 4/2013 Ota et al.  
 2013/0300639 A1\* 11/2013 Kim ..... G09G 3/3233  
 345/83

FOREIGN PATENT DOCUMENTS

JP 2009-288435 A 12/2009  
 JP 2009-300752 A 12/2009  
 JP 2010-078946 A 4/2010  
 JP 2011-039269 A 2/2011  
 JP 2011-053635 A 3/2011

OTHER PUBLICATIONS

Dec. 24, 2014 Office Action issued in U.S. Appl. No. 13/669,897.  
 Feb. 1, 2018 Notice of Allowance issued in U.S. Appl. No. 13/669,897.  
 Jun. 23, 2015 Advisory Action issued in U.S. Appl. No. 13/669,897.  
 Sep. 3, 2015 Advisory Action issued in U.S. Appl. No. 13/669,897.

\* cited by examiner

FIG. 1

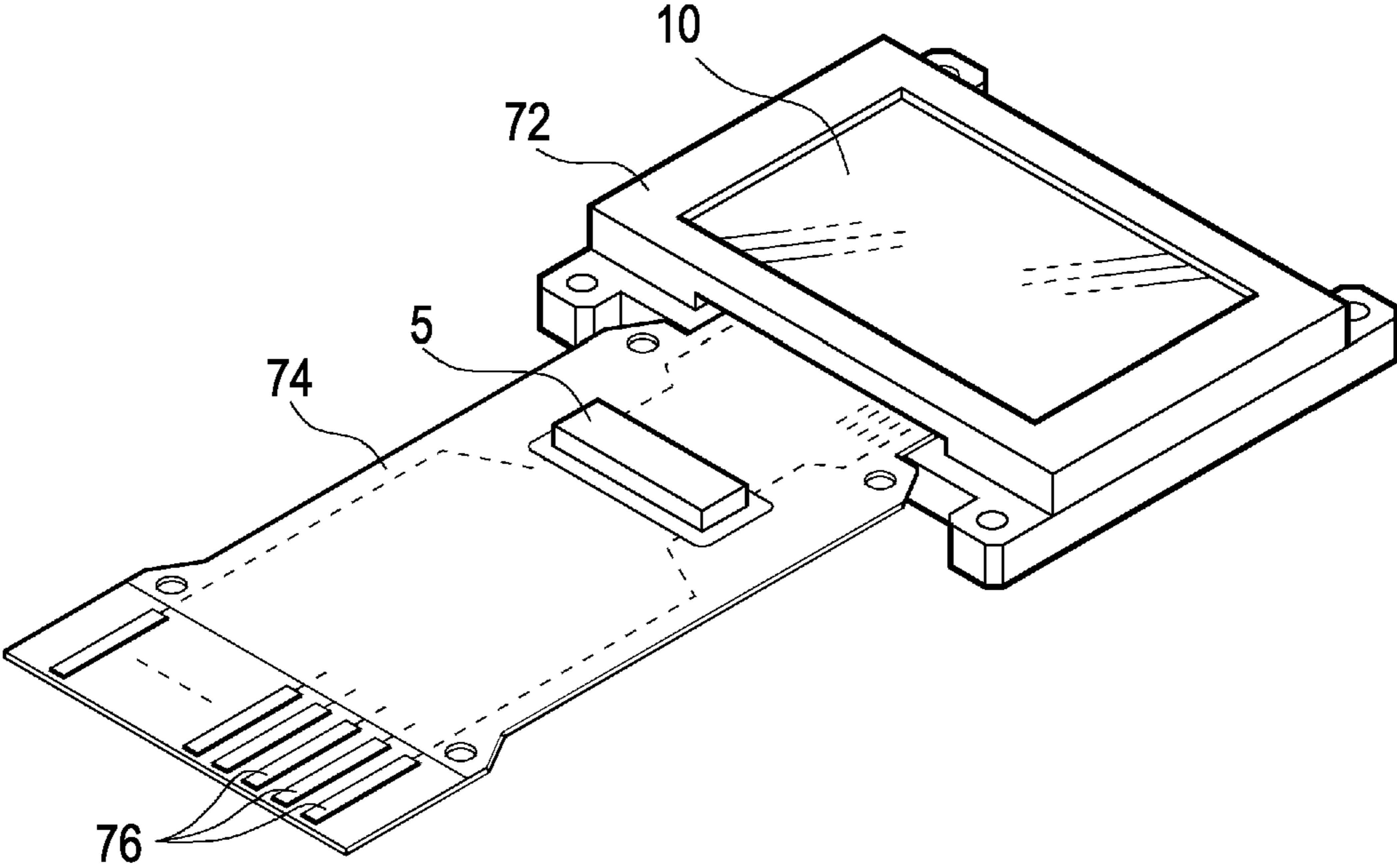




FIG. 2

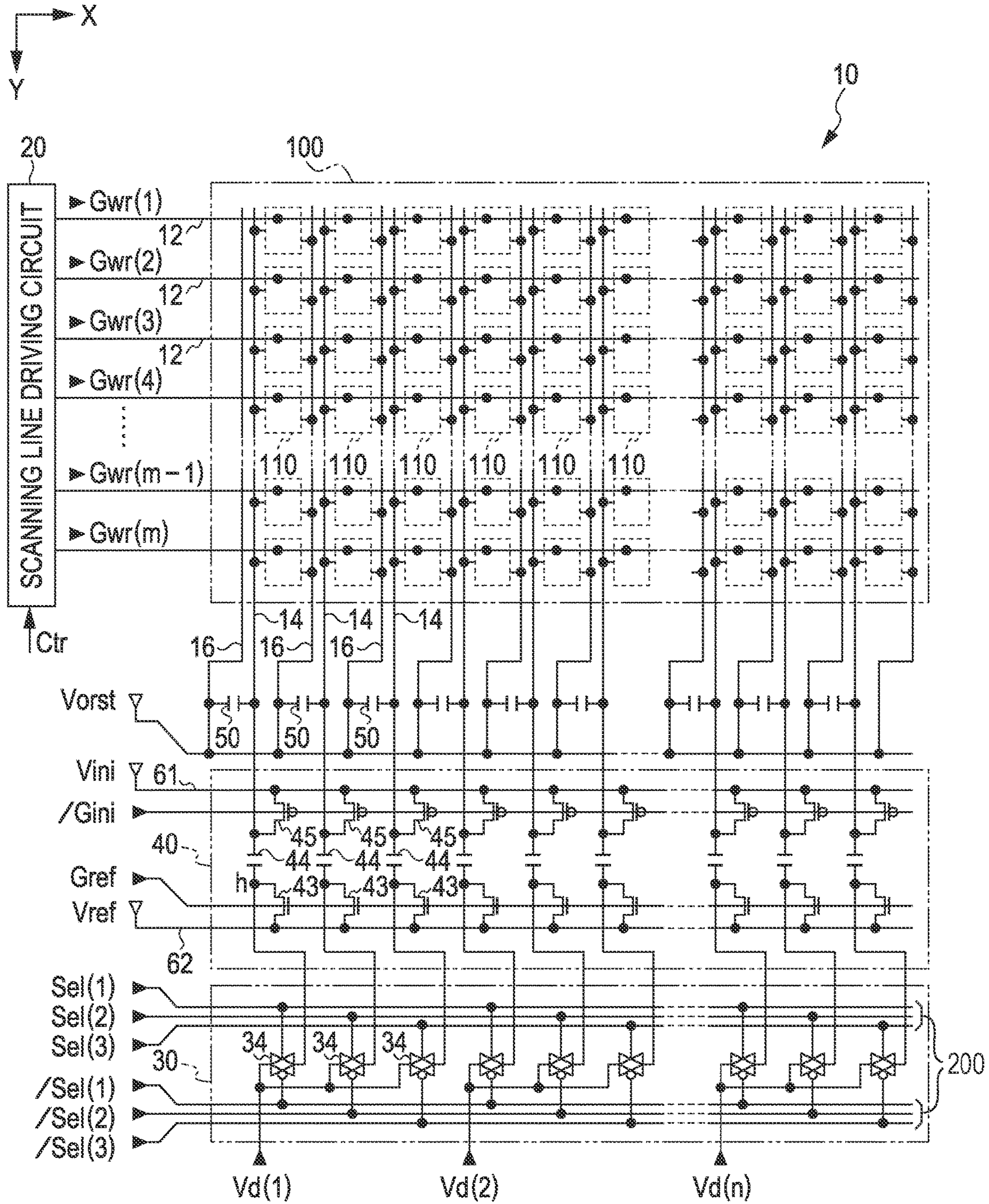


FIG. 3

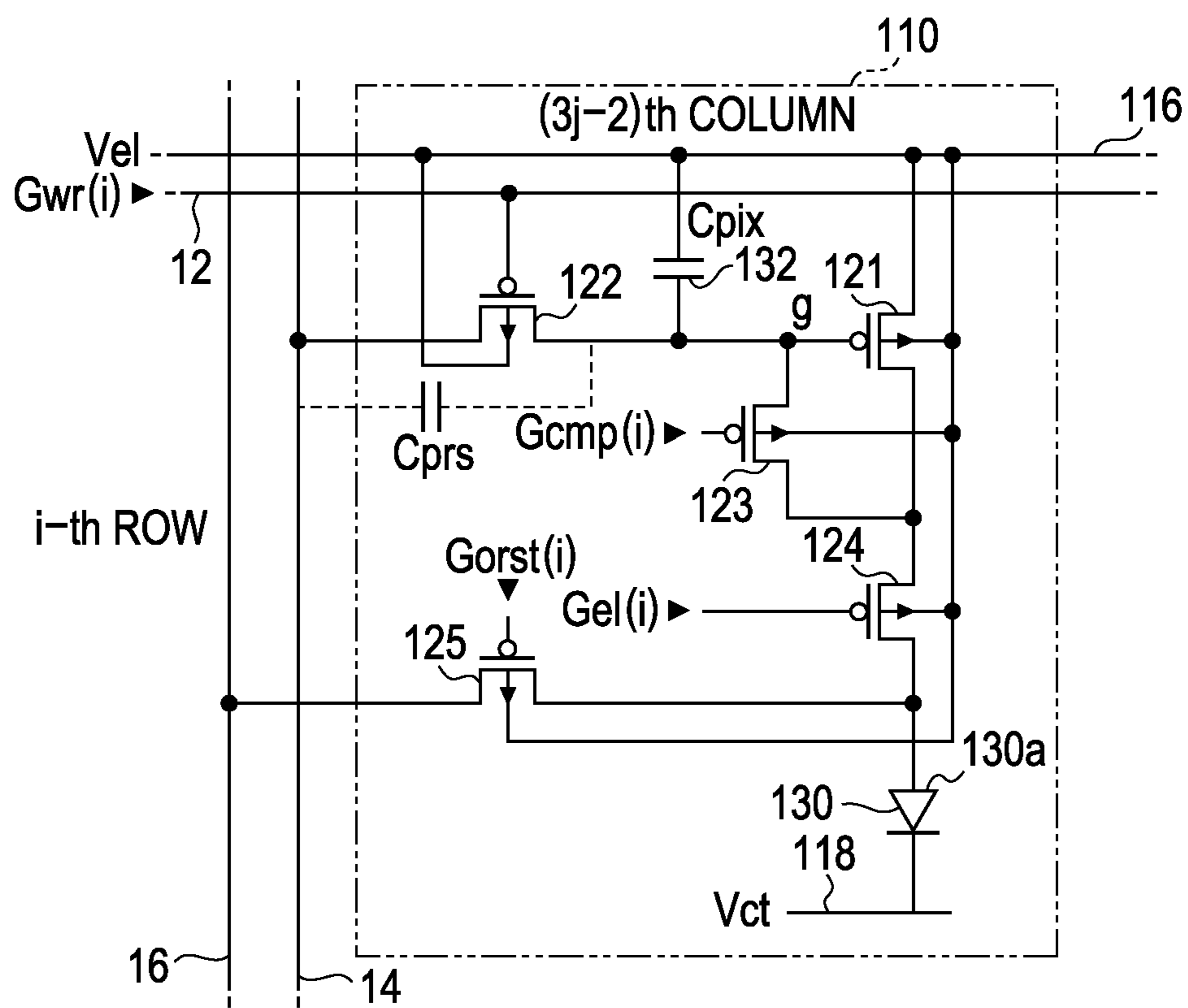




FIG. 4

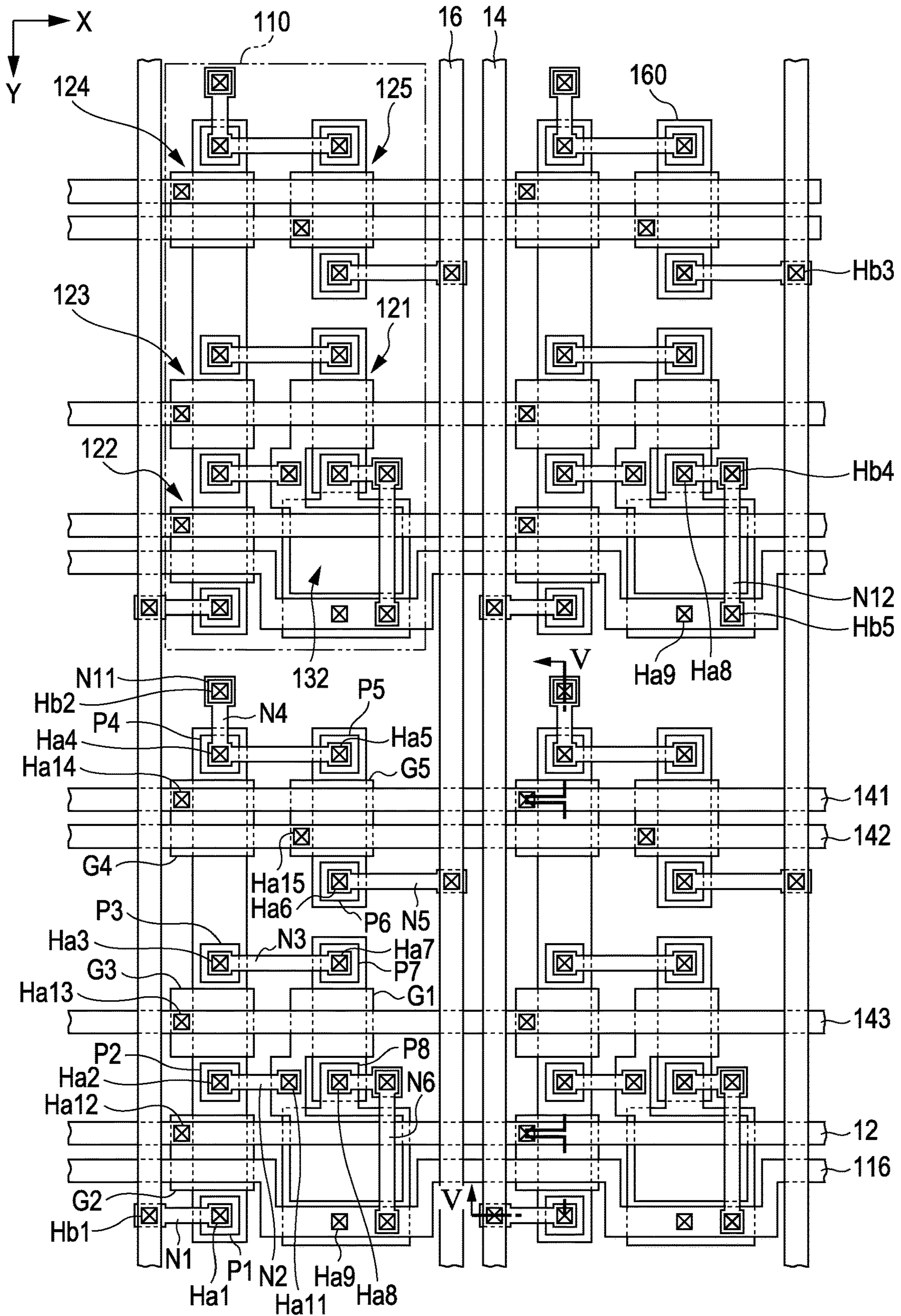


FIG. 5

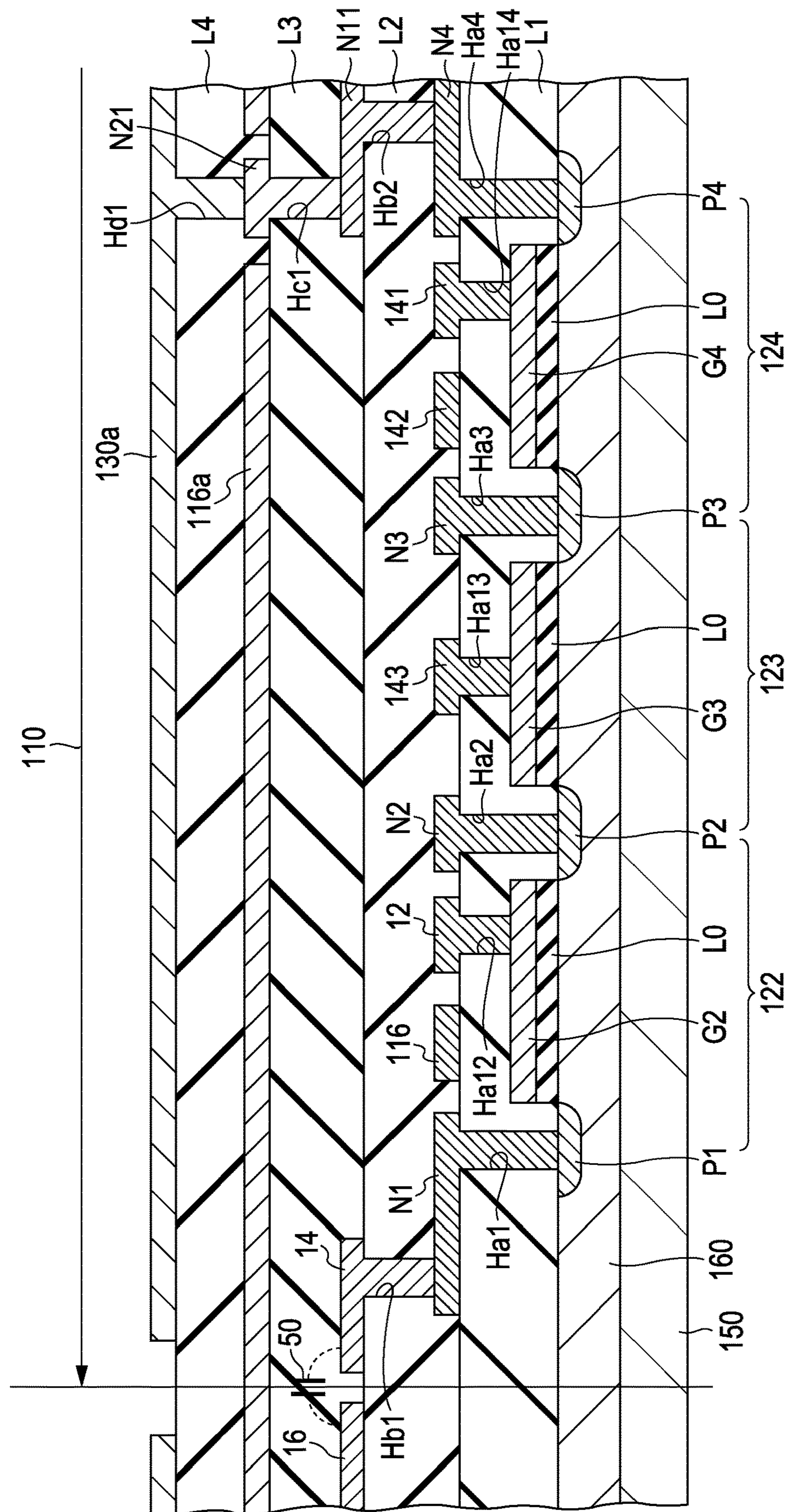




FIG. 6

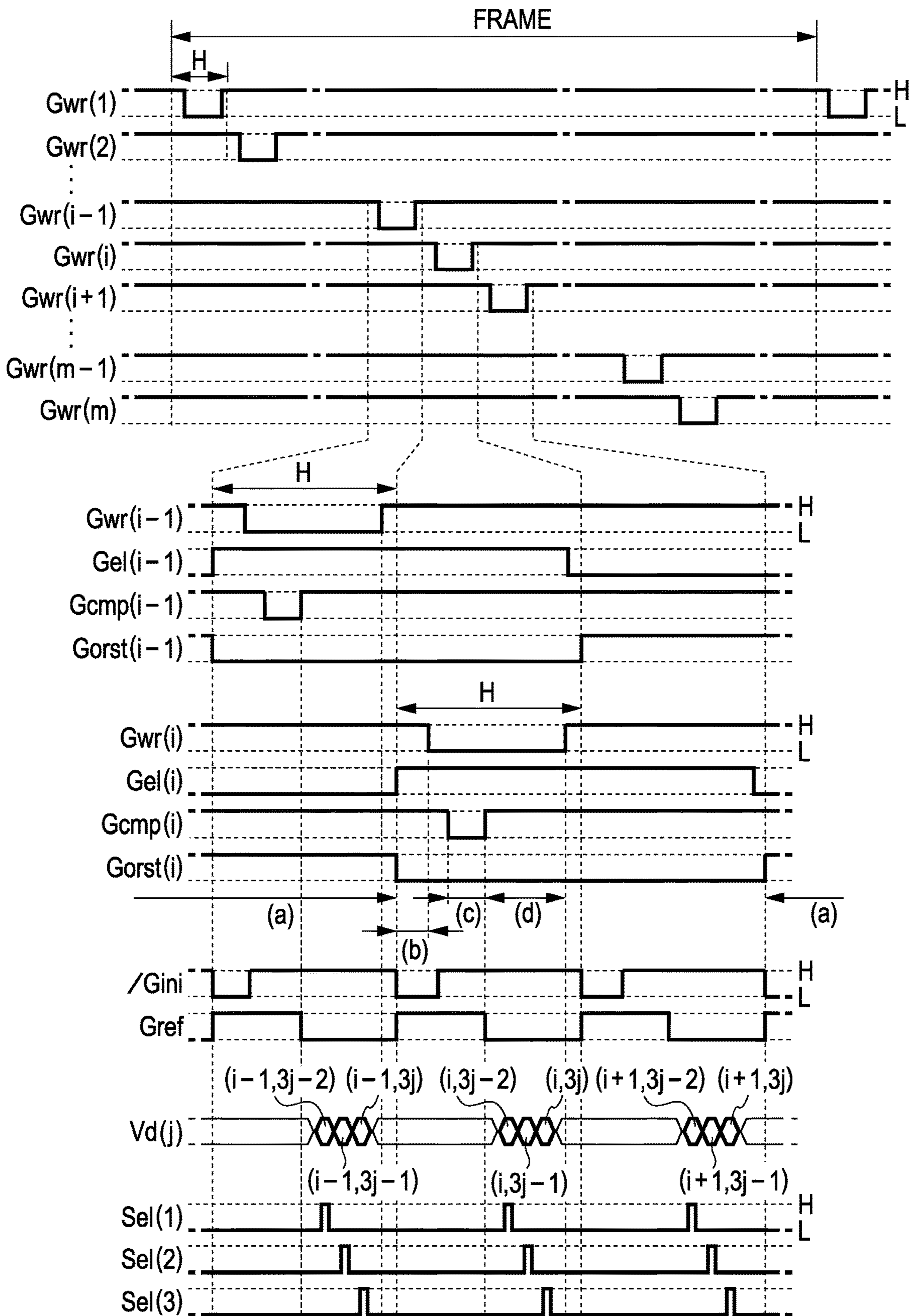




FIG. 7

<(a) LIGHT EMITTING PERIOD>

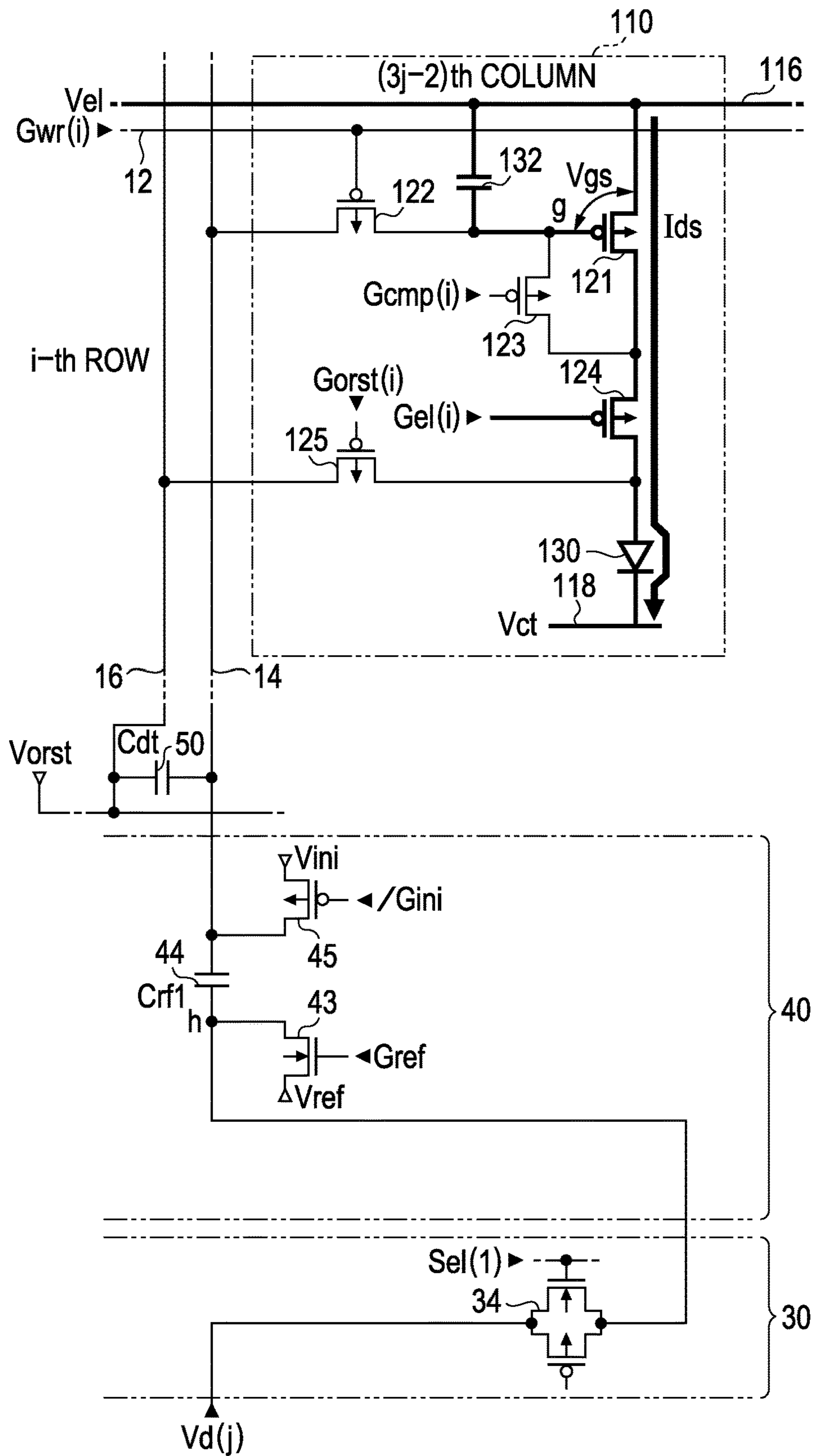


FIG. 8

<(b) INITIALIZATION PERIOD>

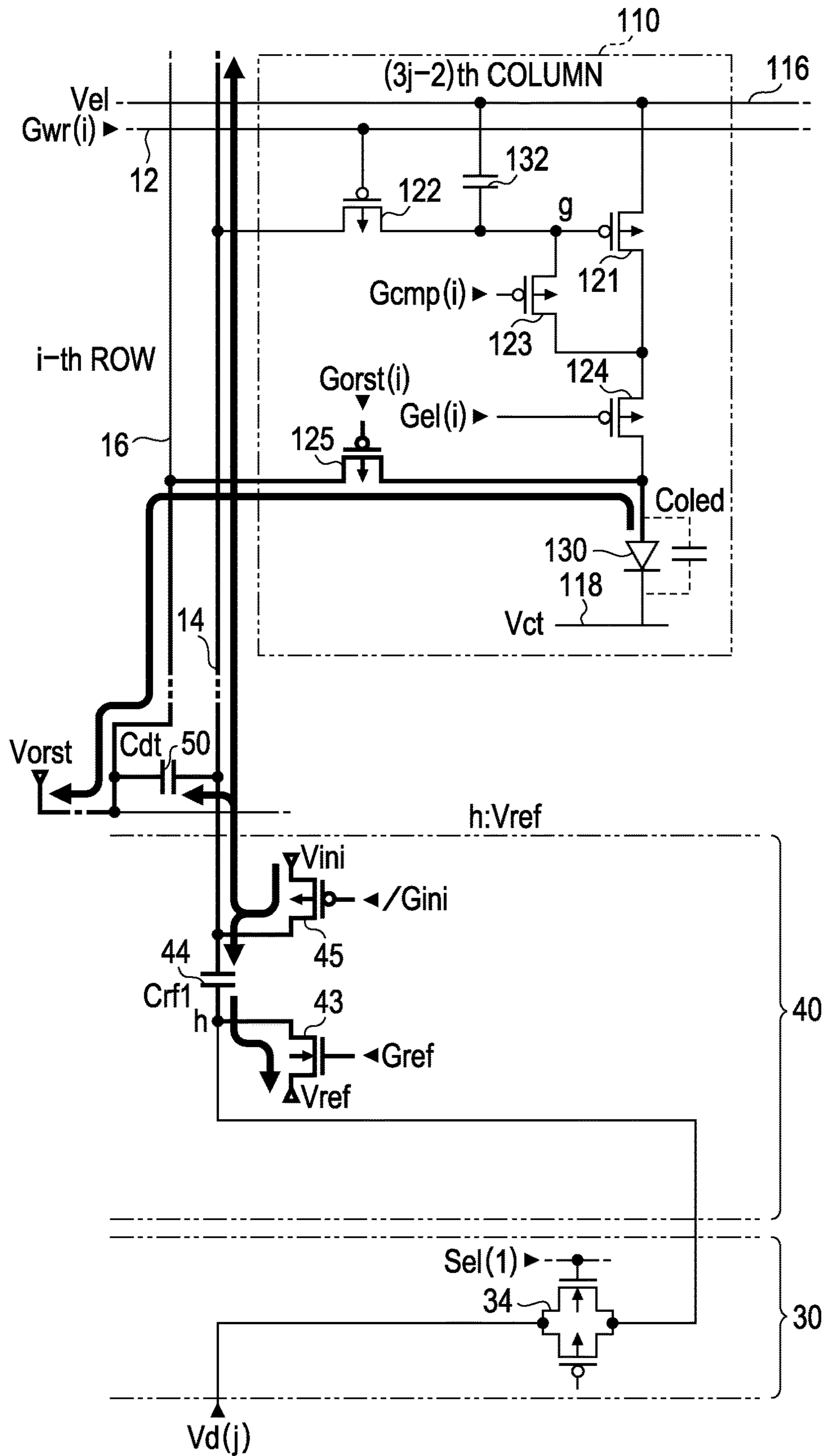


FIG. 9

<(c) COMPENSATION PERIOD>

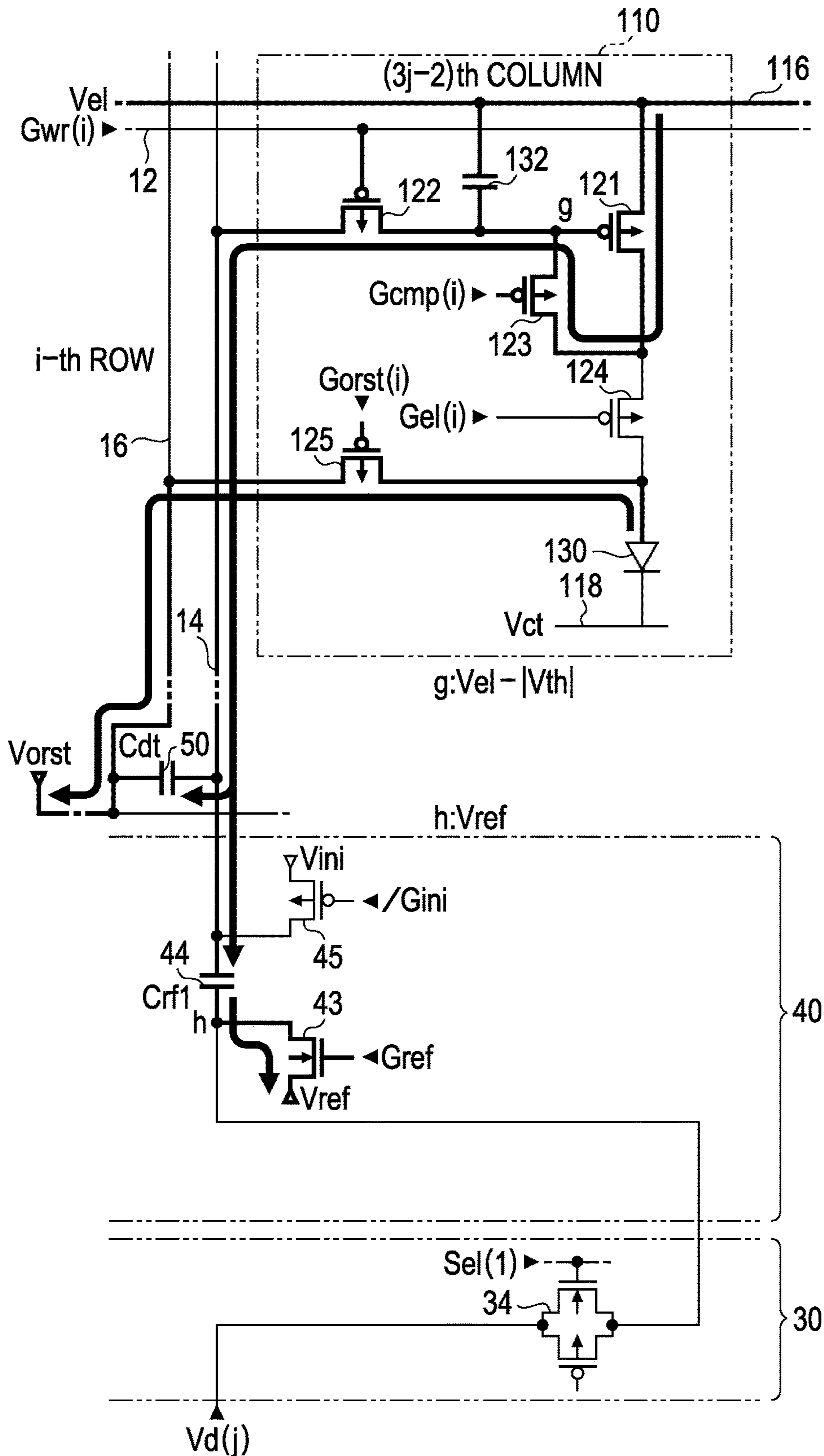




FIG. 10  
<(d) WRITING PERIOD>

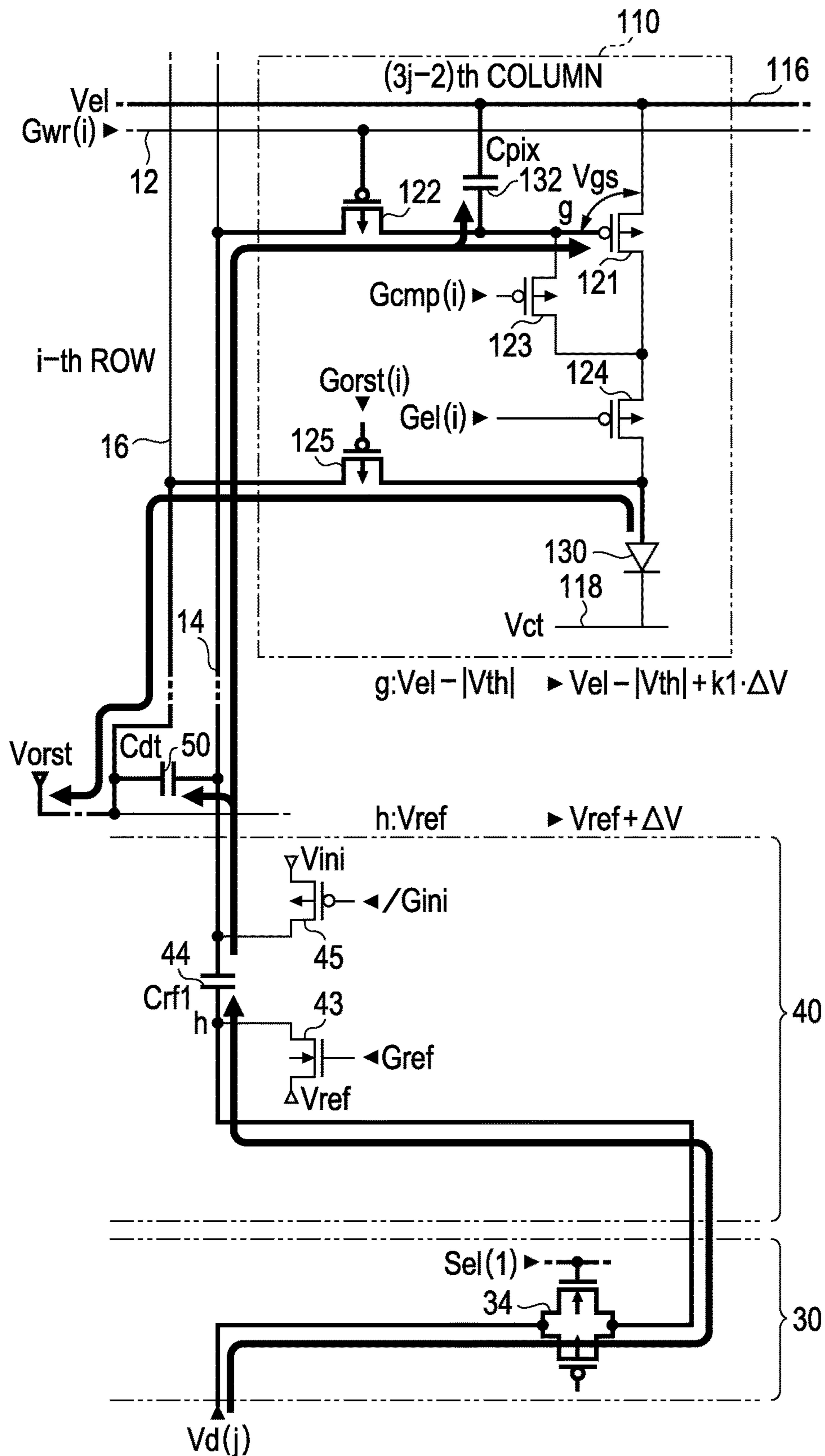


FIG. 11

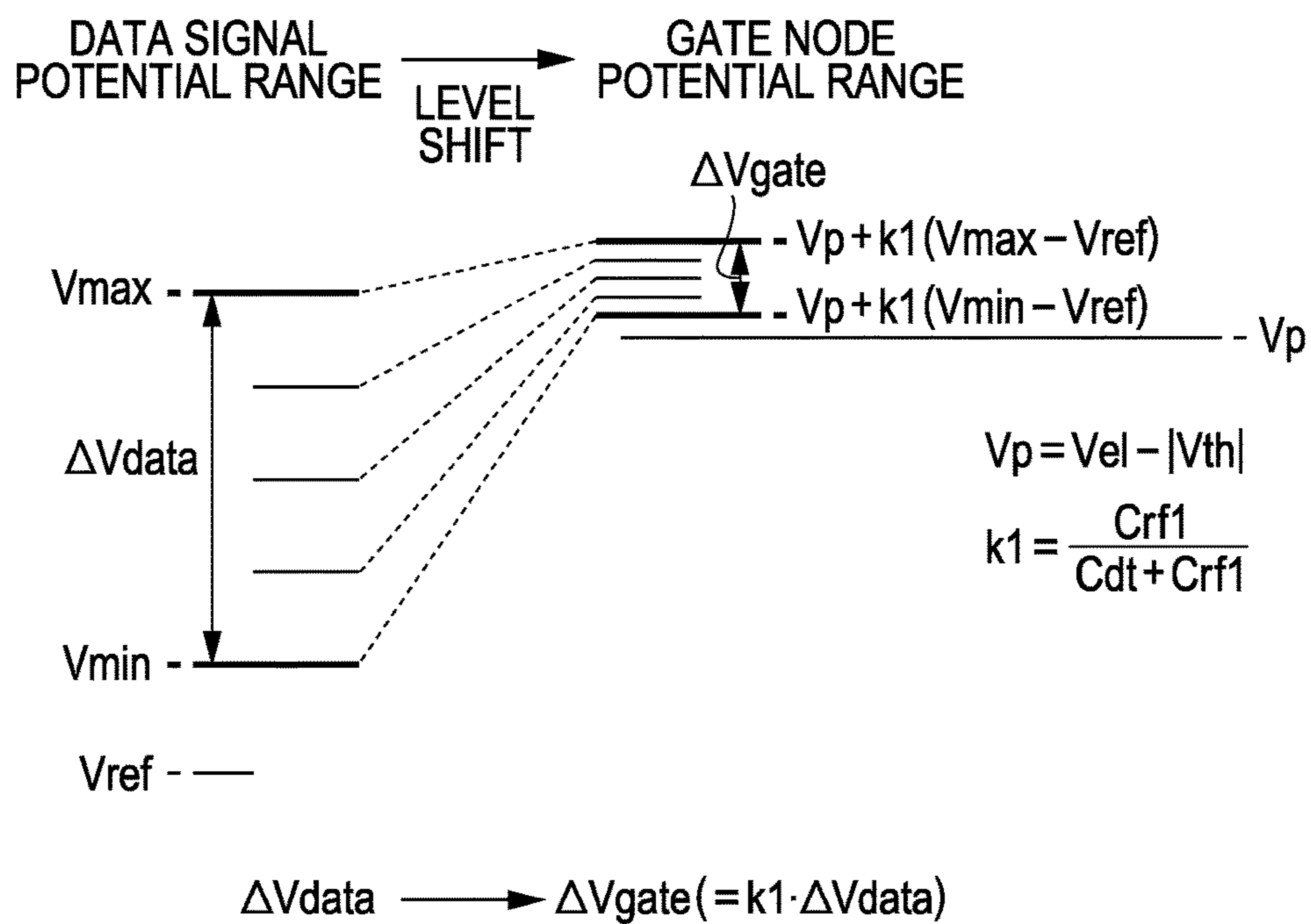


FIG. 12

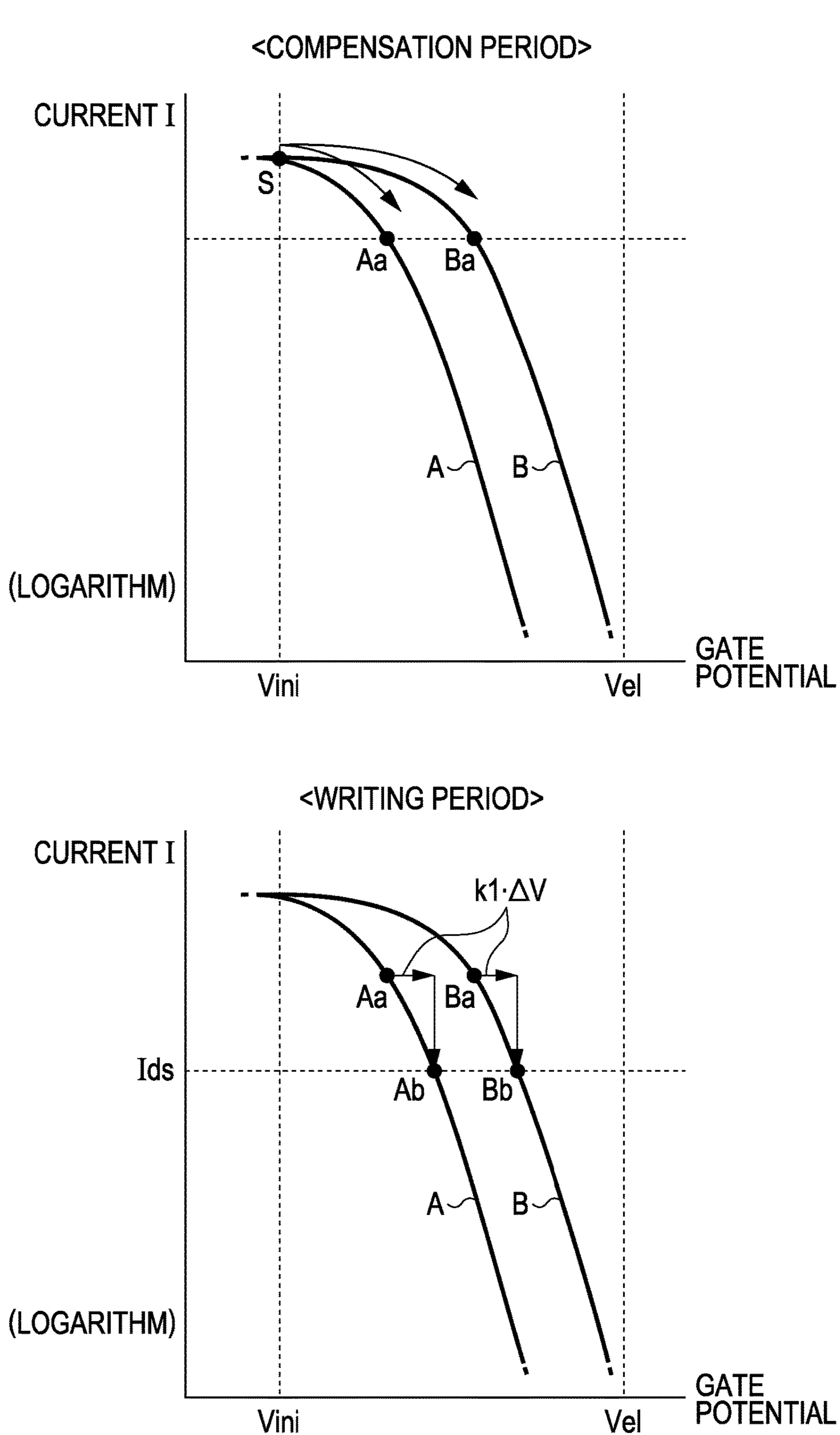




FIG. 13

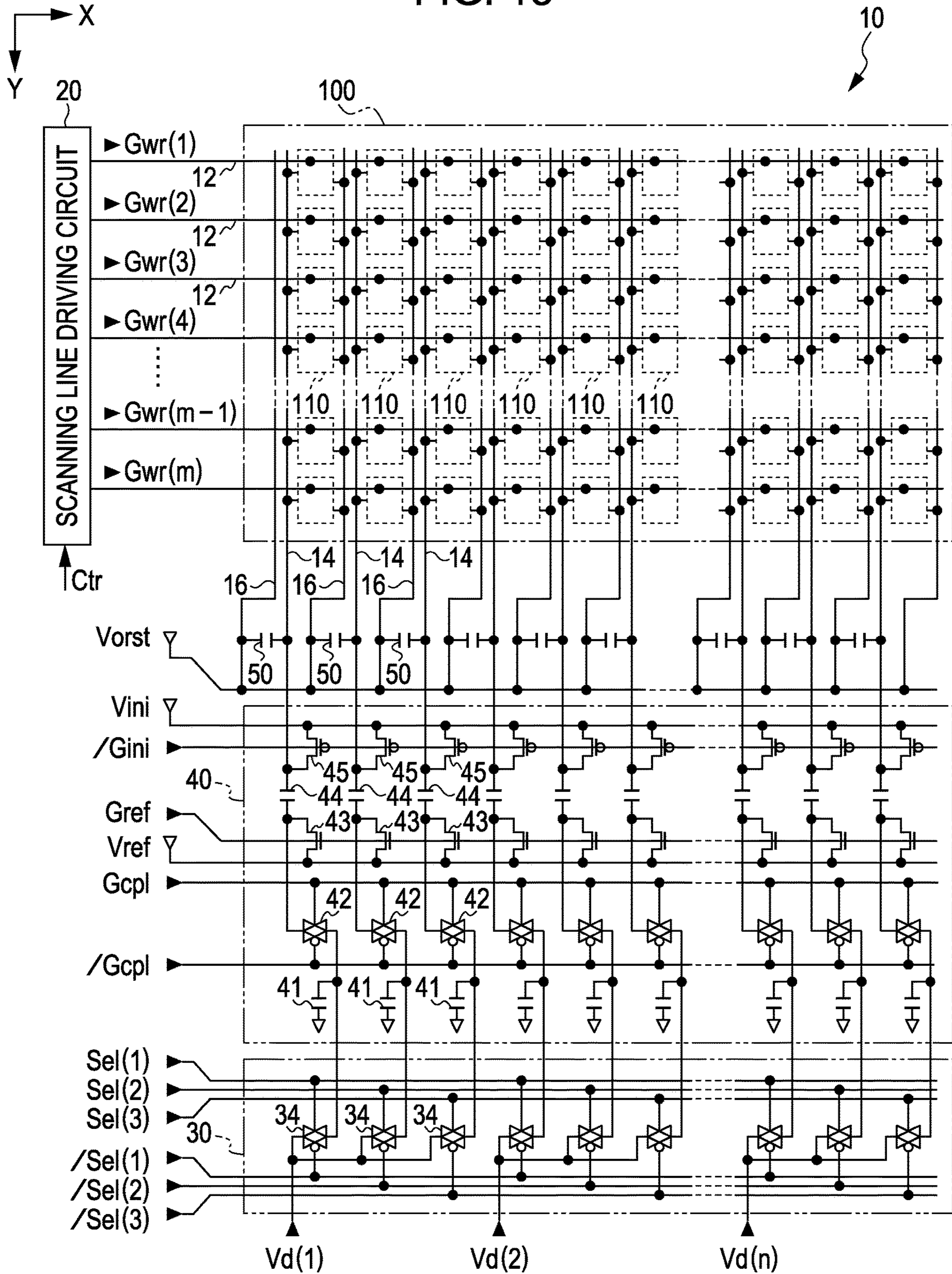


FIG. 14

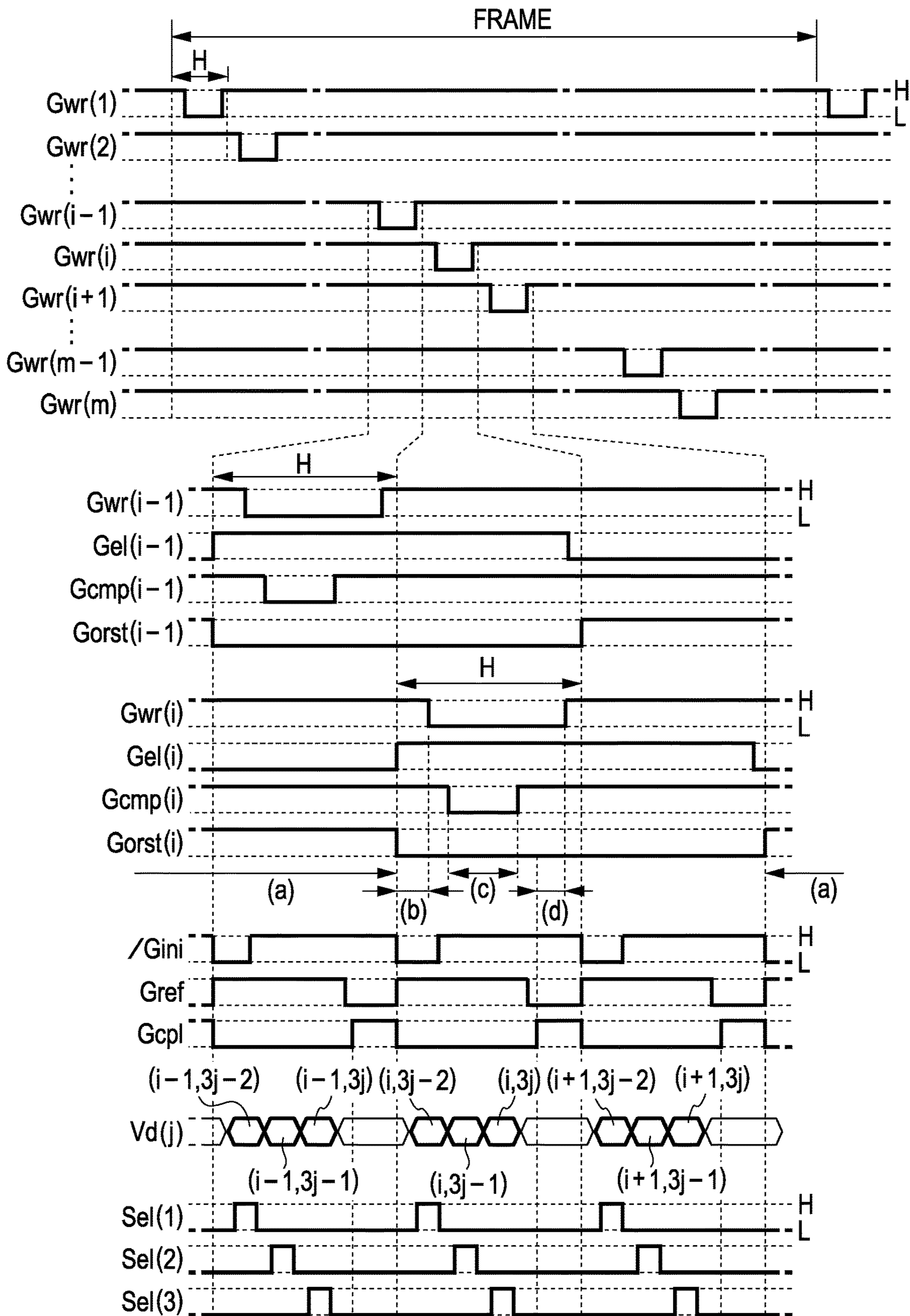


FIG. 15

<(a) LIGHT EMITTING PERIOD>

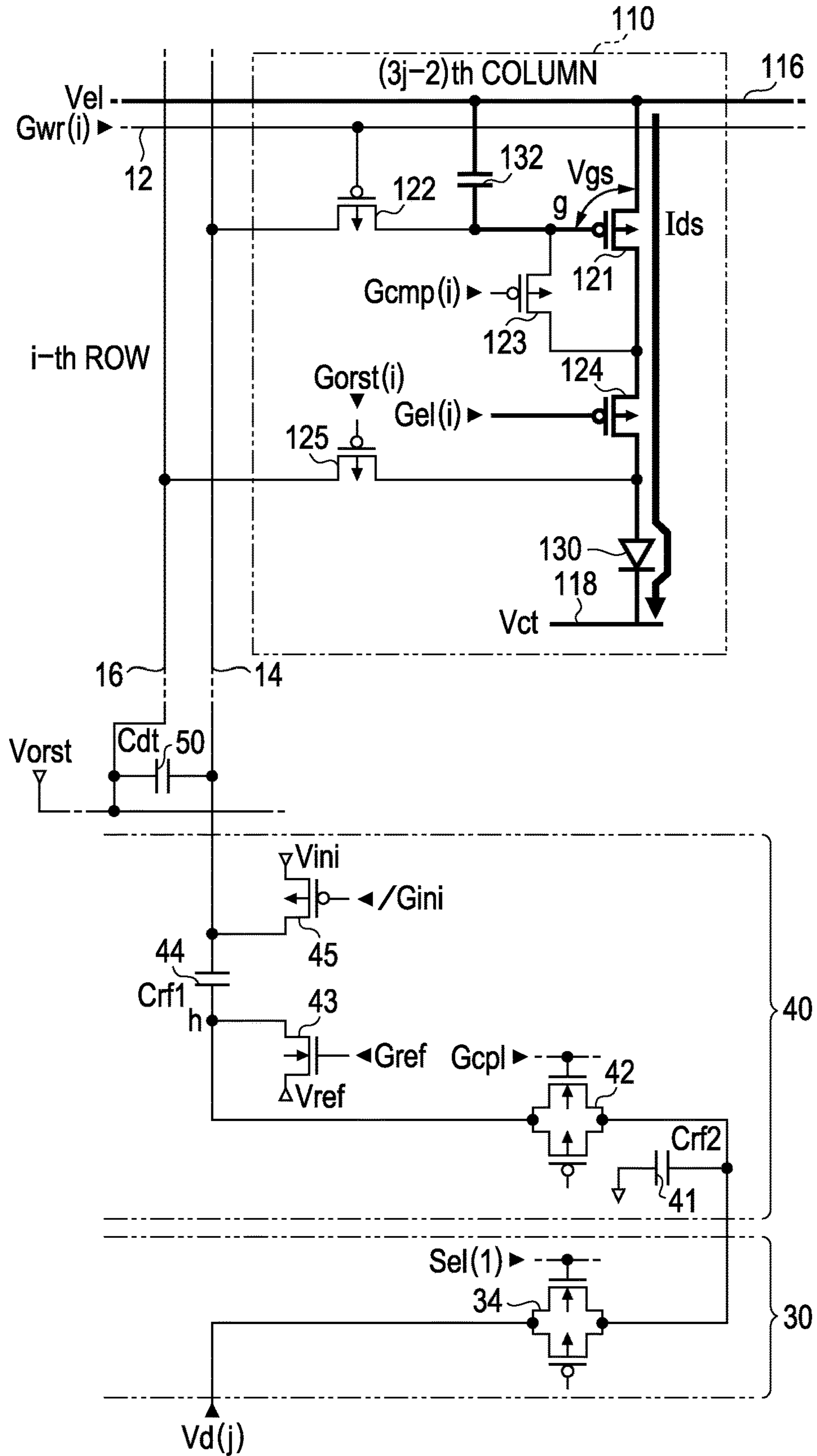




FIG. 16

<(b) INITIALIZATION PERIOD>

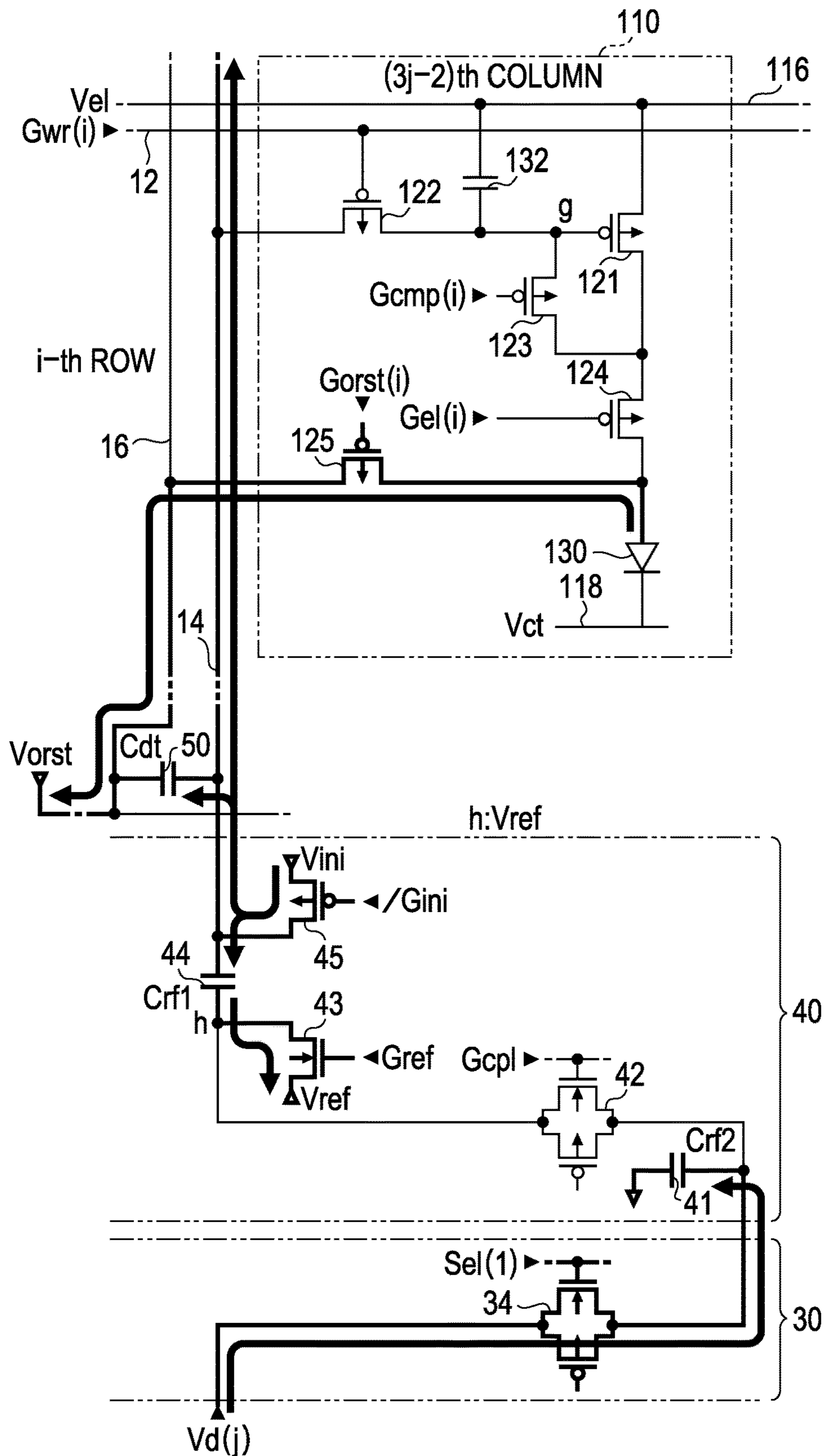


FIG. 17

<(c) COMPENSATION PERIOD>

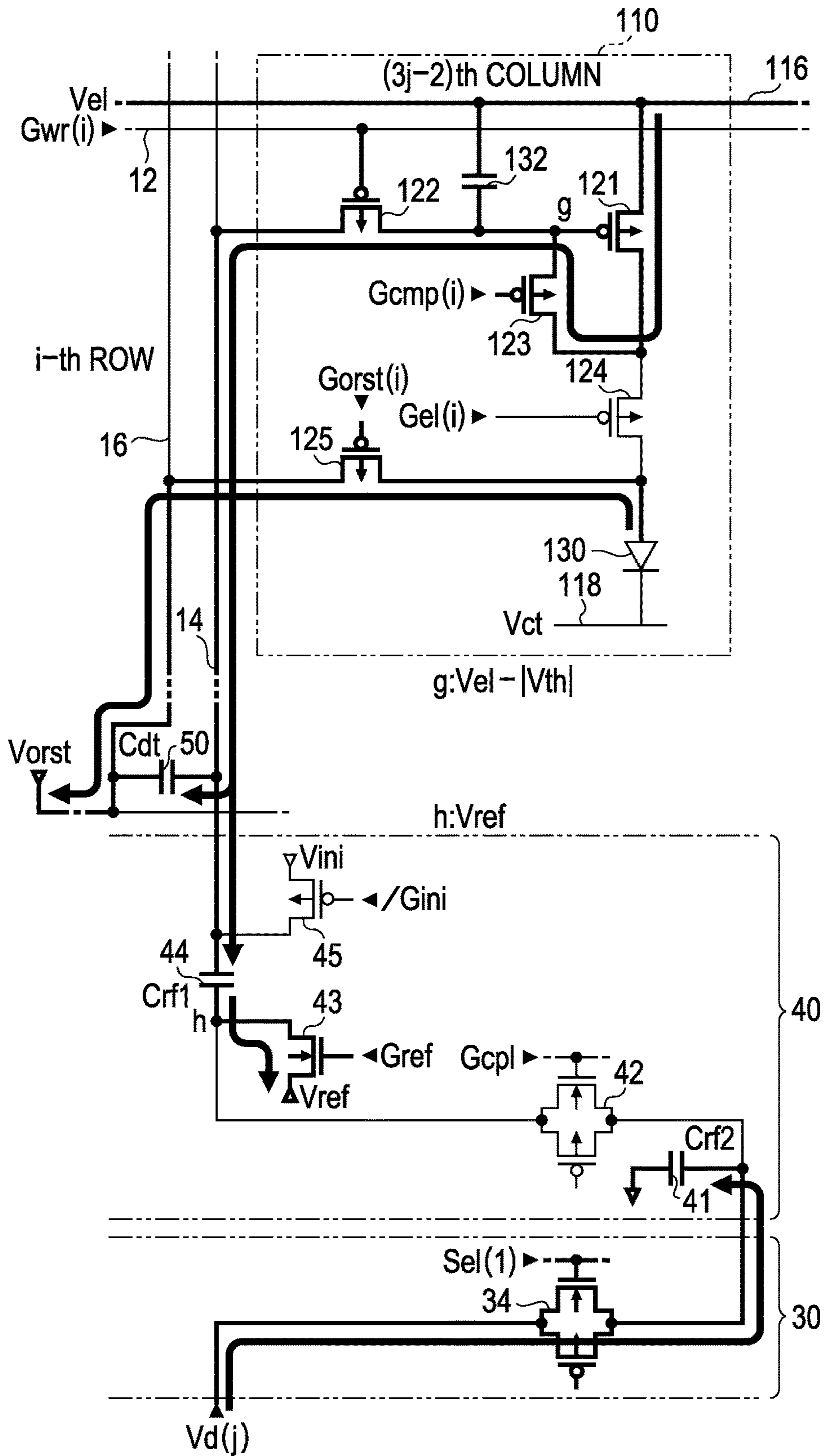


FIG. 18  
<(d) WRITING PERIOD>

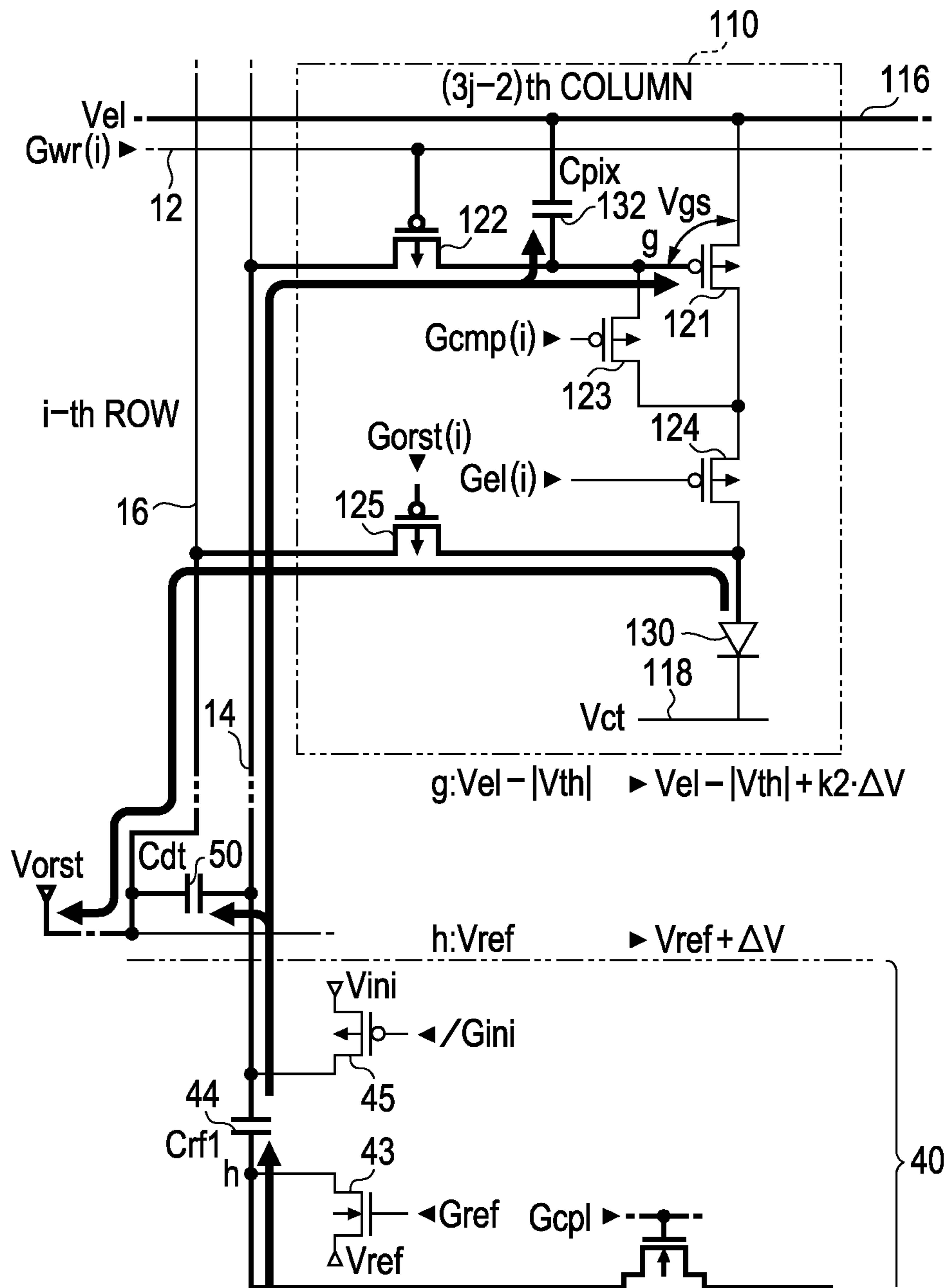




FIG. 19

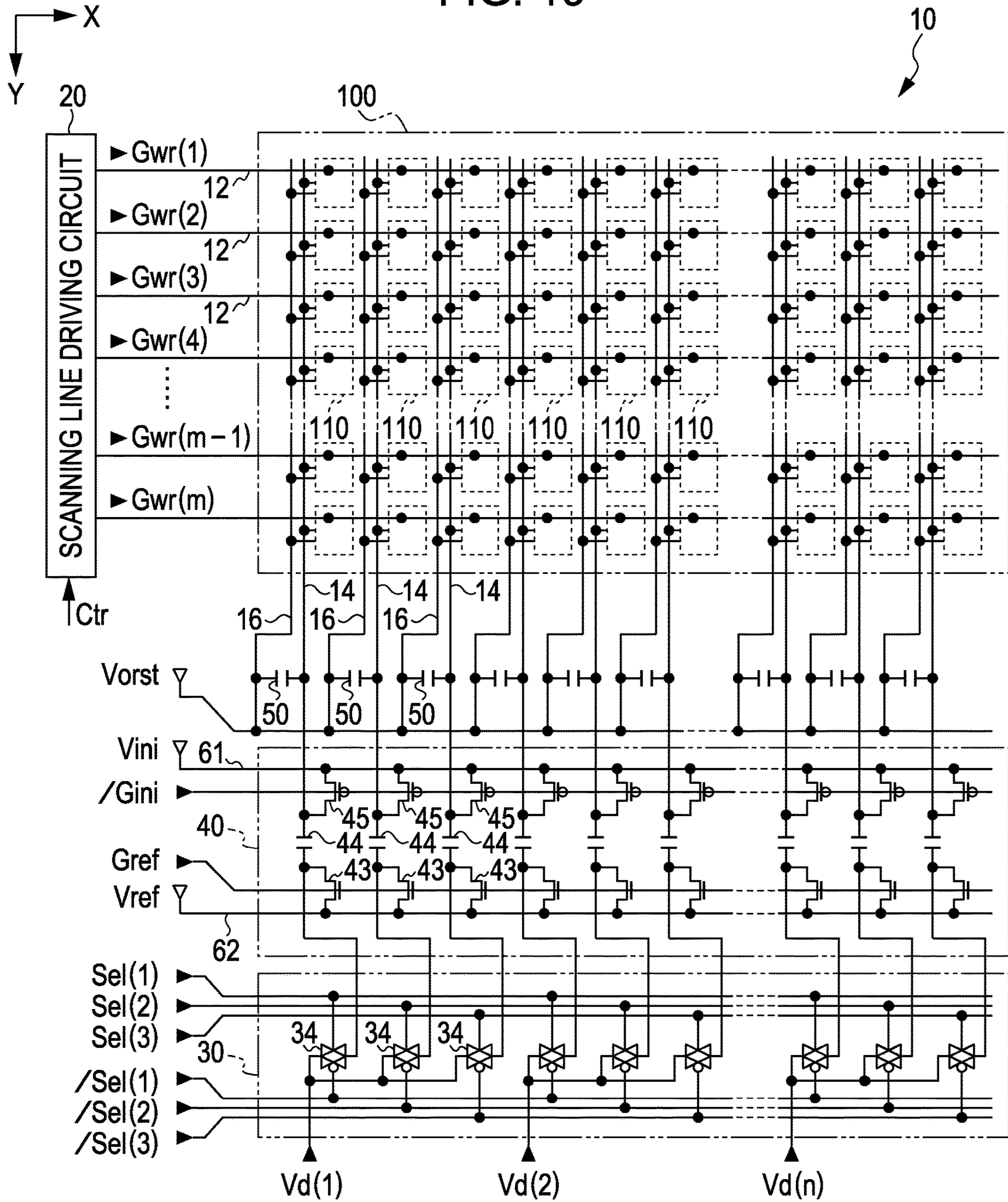


FIG. 20

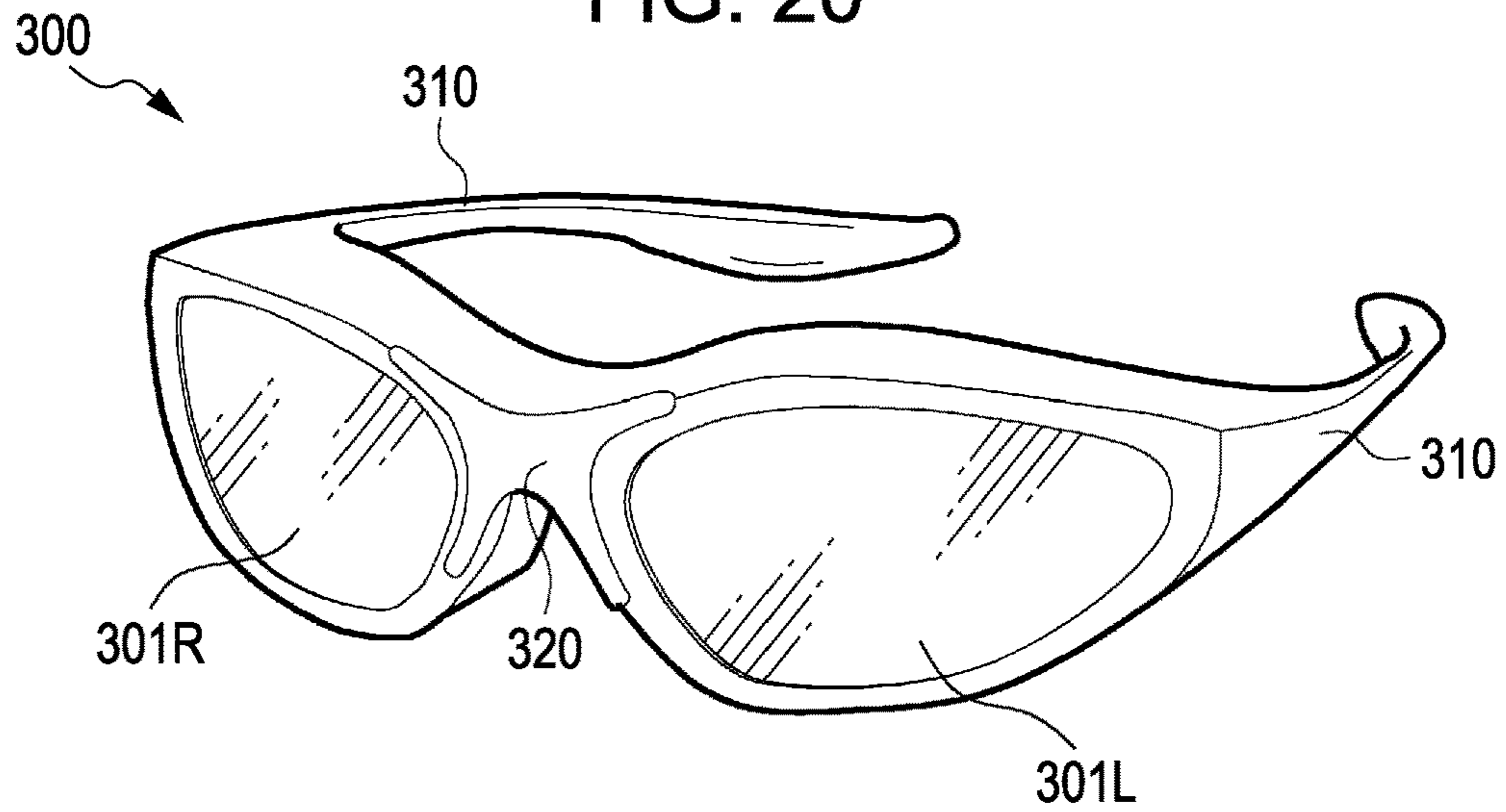
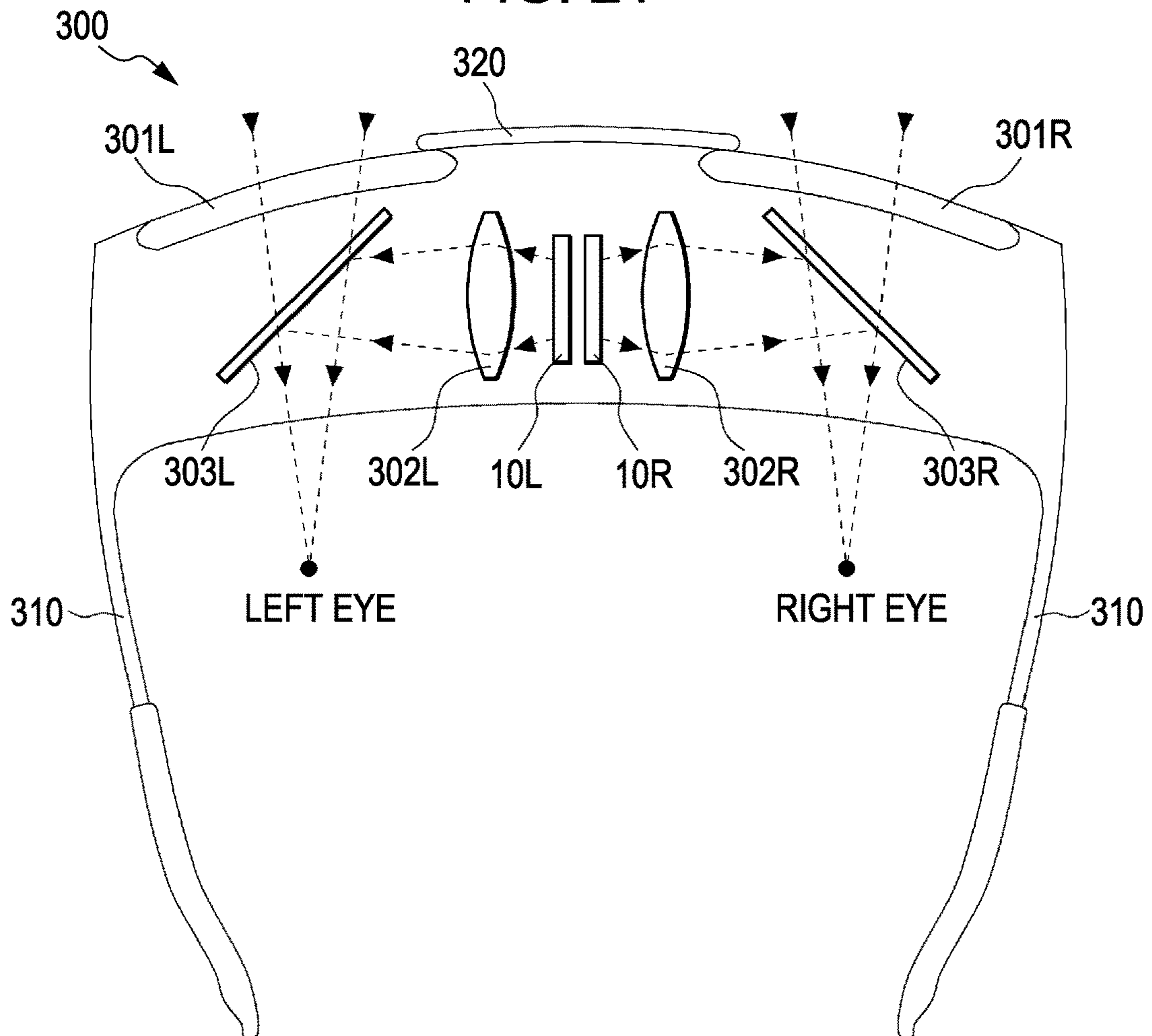


FIG. 21





**ELECTRO-OPTICAL DEVICE HAVING A  
STORAGE CAPACITOR FORMED BY A  
DATA LINE AND A POTENTIAL LINE**

CROSS-REFERENCE

This is a Continuation of U.S. application Ser. No. 16/585,983, filed Sep. 27, 2019, which is a Continuation of U.S. application Ser. No. 16/393,200, filed Apr. 24, 2019, which is a Continuation of U.S. application Ser. No. 15/959,765, filed Apr. 23, 2018, which is a Continuation of U.S. application Ser. No. 13/669,897, filed Nov. 6, 2012, and claims priority to Japanese Patent Application No. 2011-250386, filed Nov. 16, 2011. The entire contents of the above applications are expressly incorporated by reference herein.

BACKGROUND

1. Technical Field

The present invention relates to an electro-optical device and an electronic apparatus useful when a pixel circuit is miniaturized, for example.

2. Related Art

In recent years, various types of electro-optical devices using light-emitting elements such as organic light emitting diodes (below, "OLED") have been proposed. In such electro-optical devices, pixel circuits including the above-described light-emitting elements, transistors, and the like corresponding to intersections of scanning lines and data lines are generally configured to be provided corresponding to the pixels of the image to be displayed. In such a configuration, when a data signal of a potential according to the gradation level of the pixels is applied to the gate of the transistor, the transistor supplies current according to the voltage between the gate and the source to the light-emitting element. In this manner, the light-emitting element emits light with a luminance according to the gradation level.

For such electro-optical devices, there is great demand for reduction of the display size and an increase in the high definition of the display. In order to achieve both reduction of the display size and an increase in the high definition of the display, since there is a need to miniaturize the pixel circuit, a technique providing the electro-optical device on a silicon integrated circuit, for example, has also been proposed (for example, refer to JP-A-2009-288435).

Here, when the pixel circuit is miniaturized, it is necessary to control the current supplied to the light-emitting element within a micro region. The current supplied to the light-emitting element is controlled according to the voltage between the gate and the source of the transistor; however, in the micro region, the current supplied to the light-emitting element changes greatly with respect to slight changes in the voltage between the gate and the source.

Meanwhile, the driving ability of the circuit outputting the data signal is increased in order to charge the data lines in a short time. In a circuit having such a high driving ability, it is difficult to output data signals with extremely fine precision.

Further, when the pixel circuit is miniaturized, luminance unevenness caused by errors generated during manufacturing is generated and this has led to deterioration in the display quality in some cases.

SUMMARY

An advantage of some aspects of the invention is that it provides an electro-optical device, and an electronic appa-

ratus for which a highly precise data signal is not necessary, and which are capable of supplying current to a light-emitting element with high precision while suppressing the generation of luminance unevenness.

5 According to an aspect of the invention, there is provided an electro-optical device including: a plurality of scanning lines extending in a first direction; a plurality of data lines extending in a second direction; a plurality of potential lines extending in the second direction; a plurality of pixel circuits  
10 provided corresponding to intersections of the plurality of scanning lines and the plurality of data lines; and a driving circuit driving the plurality pixel circuits, in which each of the plurality of pixel circuits includes a driving transistor having a first gate, a first source, and a first drain, the driving  
15 transistor controlling a current level according to the voltage between the first gate and the first source, a writing transistor electrically connected between the first gate of the driving transistor and the data lines, a first storage capacitor of which one end is electrically connected to the gate of the  
20 driving transistor and which holds the voltage between the first gate and source of the driving transistor, and a light-emitting element emitting light at a luminance according to the current level, a predetermined potential is supplied to each of the plurality of potential lines, and, in the plurality  
25 of data lines and the plurality of potential lines, a second storage capacitor holding the potential of the data lines is formed by the data lines and the potential lines which are adjacent to each other.

According to the aspect of the invention, the second storage capacitor is formed by data lines and potential lines which are adjacent to each other. Since the data lines and potential lines are provided from one end to the other end of a region provided with a plurality of pixel circuits, the second storage capacitor has a sufficiently large capacitance in comparison with the first storage capacitor provided in the pixel circuit. Further, variation in the capacitance of the second storage capacitors of each column depends on errors in the semiconductor processing; however, since the second storage capacitor is formed by electrodes having a large area  
30 such as the data lines and the potential lines, it is possible to reduce the relative variation of the capacitance of the second storage capacitor.

Here, when the writing transistor is turned on, the gate of the driving transistor is electrically connected with the data lines, the first storage capacitor, and the second storage capacitor. Accordingly, for example, in a case where the potential of the gate of the writing transistor is determined by supplying a charge to the first storage capacitor and the second storage capacitor through the data lines, the potential  
45 of the gate of the driving transistor is determined according to the size of the first storage capacitor and the charge accumulated in the capacitance thereof and the size of the second storage capacitor and the charge accumulated in the capacitance thereof. More specifically, the charge supplied through the data lines is distributed to the first storage capacitor and the second storage capacitor; however, since the second storage capacitor has a sufficiently large capacitance in comparison with the first storage capacitor, the voltage of the gate of the driving transistor is substantially  
50 determined according to the charge accumulated in the second storage capacitor and the capacitance of the second storage capacitor.

As described above, since the variation of the capacitance of each of the plurality of second storage capacitors provided corresponding to each of the plurality of data lines is small, it is also possible to suppress variation in each column of the voltage of the gate of the driving transistor to be small.



Accordingly, the electro-optical device according to the aspect suppresses the generation of display unevenness and is capable of high quality display.

In addition, it is preferable that the above-described electro-optical device further include a third storage capacitor having one end connected to the data line and another end, the other end of the third storage capacitor is configured such that a data signal having a potential regulating a luminance of the light-emitting element is supplied to the other end of the third storage capacitor.

According to the aspect of the invention, the data signal of the potential regulating the luminance of the light-emitting element is supplied to one end of the third storage capacitor. The data lines are connected to the other end of the third storage capacitor and configure one end of the second storage capacitor. Accordingly, the range of potential fluctuations of the data lines becomes a value in which the range of potential fluctuations of the data signals is compressed according to the capacitance ratio of the third storage capacitor with respect to the second storage capacitor. Since the second storage capacitor formed by the data lines and the potential lines has a large capacitance, the range of potential fluctuations of the data lines can be compressed to be sufficiently small in comparison with the range of potential fluctuations of the data signals. In this manner, even without cutting up the data signals with fine precision, it is possible to supply the current with respect to the light-emitting element with good precision.

Further, since the variation of the capacitance of each of the plurality of second storage capacitors provided corresponding to the plurality of data lines as described above is small, it is also possible to suppress the variation in the compression rate of the potential fluctuations of the data lines with respect to the potential fluctuations of the data signals to be small, and a high quality display in which the generation of luminance unevenness is prevented is possible.

In addition, it is preferable that, in the above-described electro-optical device, the pixel circuit further include an initialization transistor electrically connected between the one potential line and the light-emitting element.

According to the aspect of the invention, it is possible to suppress the influence of the holding voltage of the capacitor having a parasitic effect upon the light-emitting element.

In addition, it is preferable that, in the above-described electro-optical device, the pixel circuit further include a light-emitting control transistor electrically connected between the driving transistor and the light-emitting element, and a threshold compensation transistor electrically connected between the first gate and the first drain of the driving transistor.

According to the aspect of the invention, it is possible to set the potential of the gate of the driving transistor as a potential corresponding to the threshold voltage of the driving transistor, and it is possible to compensate for the variation of the threshold voltage of each driving transistor.

Further, in the above-described electro-optical device, the data lines and the potential lines which are adjacent to each other may be configured to be provided between two pixel circuits adjacent to each other in the first direction in the plurality of pixel circuits.

In such a configuration, a form may be set in which, among the data lines and the potential lines which are adjacent to each other, the data lines are electrically connected to one of the two mutually adjacent pixel circuits, and the potential lines are electrically connected to the other of the two mutually adjacent pixel circuits.

Further, in such a configuration, a form may be set in which each of the data lines and the potential lines which are adjacent to each other is electrically connected to one of the two mutually adjacent pixel circuits.

In any configuration, since the second storage capacitor is formed by mutually adjacent data lines and potential lines, it is not necessary to make new space, and it is possible to form a large capacitance.

Here, in addition to the electro-optical device, the invention can be conceived as an electronic apparatus having the electro-optical device. Examples of the electronic apparatus typically include display apparatuses such as a head mounted display (HMD), or an electronic viewfinder.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described with reference to the accompanying drawings, wherein like numbers reference like elements.

FIG. 1 is a perspective view showing a configuration of an electro-optical device according to a first embodiment of the invention.

FIG. 2 is a view showing a configuration of the same electro-optical device.

FIG. 3 is a view showing a pixel circuit in the same electro-optical device.

FIG. 4 is a plan view showing a structure of the same electro-optical device.

FIG. 5 is a partial cross-sectional view showing the structure of the same electro-optical device.

FIG. 6 is a timing chart showing operations of the same electro-optical device.

FIG. 7 is an explanatory diagram of operations of the same electro-optical device.

FIG. 8 is an explanatory diagram of operations of the same electro-optical device.

FIG. 9 is an explanatory diagram of operations of the same electro-optical device.

FIG. 10 is an explanatory diagram of operations of the same electro-optical device.

FIG. 11 is a diagram showing amplitude compression of a data signal in the same electro-optical device.

FIG. 12 is a view showing characteristics of a transistor in the same electro-optical device.

FIG. 13 is a diagram showing the configuration of the electro-optical device according to the second embodiment.

FIG. 14 is a timing chart showing operations of the same electro-optical device.

FIG. 15 is an explanatory diagram of operations of the same electro-optical device.

FIG. 16 is an explanatory diagram of operations of the same electro-optical device.

FIG. 17 is an explanatory diagram of operations of the same electro-optical device.

FIG. 18 is an explanatory diagram of operations of the same electro-optical device.

FIG. 19 is a view showing a configuration of an electro-optical device according to a modification example of the invention.

FIG. 20 is a perspective view showing an HMD using the electro-optical device according to the embodiments and the like.

FIG. 21 is a view showing the optical configuration of the HMD.



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DESCRIPTION OF EXEMPLARY  
EMBODIMENTS

Below, aspects for embodying the invention will be described with reference to the drawings.

## First Embodiment

FIG. 1 is a perspective view showing a configuration of an electro-optical device 10 according to an embodiment of the invention.

For example, the electro-optical device 10 is a micro display displaying an image in a head mounted display. Detailed description will be given of the electro-optical device 10 later; however, the device is an organic EL apparatus in which a plurality of pixel circuits and driving circuits or the like driving the pixel circuits are formed on a silicon substrate, for example, in which an OLED which is an example of a light-emitting element is used in the pixel circuits.

The electro-optical device 10 is accommodated in an opening in a display unit or a see-through frame-shaped case 72, and one end of an FPC (Flexible Printed Circuit) substrate 74 is connected thereto. In the FPC substrate 74, a control circuit 5 of a semiconductor chip is mounted using a COF (Chip On Film) technique and a plurality of terminals 76 are provided and connected to a high-order circuit omitted from the drawings. Image data is synchronized with a synchronization signal and supplied from the high-order circuit through the plurality of terminals 76. The synchronization signal includes a vertical synchronization signal, a horizontal synchronization signal, and a dot clock signal. In addition, the image data regulates the gradation level of the pixels of the image to be displayed using 8 bits, for example.

The control circuit 5 combines the functions of a power circuit of the electro-optical device 10 and a data signal output circuit. That is, in addition to supplying each type of control signal and various types of potential generated in accordance with the synchronization signal to the electro-optical device 10, the control circuit 5 converts the digital image data to an analog data signal and performed supply thereof to the electro-optical device 10.

FIG. 2 is a view showing a configuration of the electro-optical device 10 according to the first embodiment. As shown in the drawing, the electro-optical device 10 is divided broadly into a scanning line driving circuit 20, a demultiplexer 30, a level shift circuit 40, and a display unit 100.

Among these, in the display unit 100, pixel circuits 110 corresponding to the pixels of the image to be displayed are arranged in a matrix shape. In detail, as shown in FIG. 2, in the display unit 100, m rows of scanning lines 12 are provided to extend in the X direction (first direction), and, (3n) columns of data lines 14 grouped in threes are provided to extend in the Y direction (second direction) and preserve the electrical insulation between each of the scanning lines 12. Then, pixel circuits 110 corresponding to the intersection portions between the m rows of scanning lines 12 and the (3n) columns of data lines 14 are provided. For this reason, in the present embodiment, the pixel circuits 110 are arranged in a matrix shape with m rows vertically and (3n) columns horizontally.

Here, m and n are both natural numbers. In the matrix of the scanning lines 12 and the pixel circuit 110, in order to distinguish the rows, there are cases where the rows are referred to as 1, 2, 3, . . . , (m-1), and m in order from the top of the drawing. In the same manner, in order to distin-

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guish between the columns of the matrix of the data lines 14 and the pixel circuits 110, there are cases where the columns are referred to as 1, 2, 3, . . . , (3n-1), and (3n) in order from the left of the drawing. In addition, when the integer j of 1 or more to n or less is used in order to generalize and explain the groups of the data lines 14, it signifies that the data lines 14 of the (3j-2) column, the (3j-1) column, and the (3j) column belong to the j-th group counted from the left.

Here, three pixel circuits 110 corresponding to the intersections of the scanning lines 12 of the same row and three columns of the data lines 14 belonging to the same group respectively correspond to pixels of R (red), G (green), and B (blue), and these three pixels express one dot of the color image to be displayed. That is, in the present embodiment, a color of one dot is configured to be expressed using additive color mixing according to the emitted light of the OLED corresponding to RGB.

Further, as shown in FIG. 2 in the display unit 100, potential lines 16 of (3n+1) column extend in the Y direction (second direction) and are provided to preserve the mutual electrical insulation with the scanning lines 12. A predetermined potential Vorst is supplied in common to each potential line 16 as a reset potential. Here, since the columns of the potential lines 16 are divided, they will sometimes be referred to as the potential lines 16 of the 1, 2, 3, . . . , (3n), and (3n+1) columns in order from the left in the drawing.

Each of the potential lines 16 of the first column to the (3n)-th column is provided along each of the data lines 14 of the first column to the (3n)-th column. That is, when an integer of 1 or more and (3n) or less is set as p, the potential lines 16 of the p-th column and the data lines 14 of the p-th column are provided to be adjacent to each other. Among these, the potential lines 16 and the data lines 14 of the second column to the (3n)-th column are formed between two pixel circuits 110 which are adjacent to each other in the X direction.

Further, details will be given below; however, the potential lines 16 and the data lines 14 which are adjacent to each other interpose an insulating body (dielectric). Accordingly, the potential lines 16 and the data lines 14 which are adjacent to each other are capacitively coupled, and a storage capacitor 50 is formed between the two. This storage capacitor 50 functions as a second storage capacitor holding the potential of the data lines 14. Here, the distance between the potential lines 16 and the data lines 14 which are adjacent to each other is determined such that a capacitance of a necessary size can be obtained. Below, the capacitance of the storage capacitor 50 is denoted as Cdt.

In this manner, the storage capacitor 50 formed by the potential lines 16 and the data lines 14 interposing an insulating body is provided from the inside of the display unit 100 to the outside when in plan view (in other words, when viewed from a direction orthogonal to the display unit 100), or is provided inside the display unit 100. However, in FIG. 2, for convenience of description, the storage capacitor 50 is drawn so as to be provided outside of the display unit 100.

Here, the potential Vorst is supplied to the pixel circuits 110 of the first column to the (3n)-th column, respectively, through the potential lines 16 of the second column to the (3n+1)-th column.

Here, the following kind of control signal is supplied by the control circuit 5 to the electro-optical device 10 via control signal lines 200. In detail, a control signal Ctr for controlling the scanning line driving circuit 20, control signals Sel(1), Sel(2), and Sel(3) for controlling the selection with the demultiplexer 30, control signals /Sel(1), /Sel(2), and /Sel(3) which had a logic inversion relationship with



respect to these signals, a negative logic control signal/Gini for controlling the level shift circuit **40**, and a positive logic control signal Gref are supplied to the electro-optical device **10**. In addition, in practice, the control signal Ctr includes a plurality of signals such as a pulse signal or a clock signal, and an enable signal.

In addition, the data signals Vd(1), Vd(2), . . . , and Vd(n) matching the selection timing of the demultiplexer **30** are supplied to the electro-optical device **10** by the control circuit **5** corresponding to the groups numbered 1, 2, . . . , and n. Here, the maximum value of the potential that can be taken by the data signals Vd(1) to Vd(n) is set as Vmax and the minimum value is set as Vmin.

The scanning line driving circuit **20** generates scanning signals for scanning the scanning lines **12** in order one row at a time throughout the period of the frame in accordance with the control signal Ctr. Here, the scanning signals supplied to the scanning lines **12** of rows numbered 1, 2, 3, . . . , (m-1), and m are denoted as Gwr(1), Gwr(2), Gwr(3), . . . , Gwr(m-1), and Gwr(m).

Here, in addition to the scanning signals Gwr(1) to Gwr(m), the scanning line driving circuit **20** generates various types of control signals synchronized with the scanning signals for each row and performs supply thereof to the display unit **100**; however, these are not drawn in FIG. **2**. Further, the period of the frame refers to the period necessary for the electro-optical device **10** to display an image of 1 cut (frame) portion, for example, if the frequency of the orthogonal synchronization signal included in the synchronization signal is 120 Hz, the one cycle portion is a period of 8.3 milliseconds.

The demultiplexer **30** is a collection of transmission gates **34** provided for each column, and supplies data signals in order to the three columns configuring each group.

Here, the input ends of the transmission gates **34** corresponding to the columns (3j-2), (3j-1), and (3j) belonging to the j-numbered groups are mutually connected in common and respective data signals Vd(j) are supplied to the common terminals.

The transmission gates **34** provided in columns (3j-2) which are the left end columns in the j-numbered groups are turned on (conduct) when the control signal Sel(1) is the H level (control signal /Sel(1) is the L level). Similarly, the transmission gates **34** provided in columns (3j-1) which are the middle columns in the j-numbered groups are turned on when the control signal Sel(2) is the H level (when the control signal /Sel(2) is the L level) and the transmission gates **34** provided in columns (3j) which are the right end columns in the j-numbered groups are turned on when the control signal Sel(3) is the H level (when the control signal /Sel(3) is the L level).

The level shift circuit **40** has a set of the storage capacitor **44**, the P channel MOS type transistor **45**, and the N channel MOS type transistor **43** for each column, and shifts the potential of the data signals output from the output end of the transmission gate **34** of each column. Here, one end of the storage capacitor **44** is connected to a data line **14** of the corresponding column and the drain node of the transistor **45** while the other end of the storage capacitor **44** is connected to the output end of the transmission gate **34** and the drain node of the transistor **43**. For this reason, the storage capacitor **44** functions as a third storage capacitor of which one end is connected to the data lines **14** and data signals are supplied to the other end. Although omitted from FIG. **2**, the capacitance of the storage capacitor **44** is set to Crf1.

Here, the storage capacitor **44** is arranged outside the display unit **100** (in other words, in the frame area) and is

formed from two electrodes which are adjacent to each other when viewed from a direction orthogonal to the display unit **100**. In this manner, it is possible to form a large capacitance Crf1 in a comparatively narrow region, and it is possible to narrow the frame of the electro-optical device **10**.

The source nodes of the transistors **45** of each column are connected in common across each column to a power supply line **61** supplying the potential Vini as the initial potential, and the control signal /Gini is supplied in common across each column to the gate nodes. For this reason, the transistor **45** is configured so as to electrically connect the data lines **14** and the power supply lines **61** when the control signal /Gini is the L level and to perform electrical disconnection when the control signal /Gini is the H level.

In addition, the source nodes of the transistors **43** of each column are connected in common across each column to the power supply line **62** supplying the potential Vref as a predetermined potential, and the control signal Gref is supplied in common across each column to the gate nodes. For this reason, the transistor **43** is configured so as to electrically connect the node h which is the other end of the storage capacitor **44** and the power supply lines **62** when the control signal Gref is the H level and to perform electrical disconnection when the control signal Gref is the L level.

In the present embodiment, although divided into the scanning line driving circuit **20**, the demultiplexer **30** and the level shift circuit **40** for convenience, these may be conceived together as driving circuits driving the pixel circuits **110**.

Description will be given of the pixel circuits **110** with reference to FIG. **3**. Since each pixel circuit **110** has the same configuration as the others electrically, here, description will be given taking the pixel circuit **110** of the i row (3j-2) column positioned at the (3j-2)-th column of the left end side in the groups numbered j, which is an i-th row, as an example. In addition, i is a reference sign of a case generally showing rows in which the pixel circuits **110** are arranged, and is an integer of 1 or more and m or less.

As shown in FIG. **3**, the pixel circuit **110** includes P channel MOS type transistors **121** to **125**, an OLED **130**, and a storage capacitor **132**. The scanning signal Gwr(i), the control signals Gel(i), Gcmp(i), and Gorst(i) are supplied to the pixel circuits **110**. Here, the scanning signal Gwr(i), and the control signals Gel(i), Gcmp(i), and Gorst(i) are supplied by the scanning line driving circuit **20** corresponding to the respective i rows. For this reason, the scanning signal Gwr(i), and the control signals Gel(i), Gcmp(i), and Gorst(i) are also supplied in common to pixel circuits of columns other than the (3j-2) column being focused on if in the i row.

In the transistor **122**, the gate node is connected to the scanning lines **12** of the i row, and one of the drain or the source node is connected to the data lines **14** of the (3j-2)-th column, and the other is respectively connected to the gate node g in the transistor **121**, one end of the storage capacitor **132**, and one of the source or the drain of the transistor **123**. That is, the transistor **122** is electrically connected between the gate node g of the transistor **121** and the data lines **14**, controls the electrical connection between the gate node g of the transistor **121** and the data lines **14**, and functions as a writing transistor. Here, the gate node of transistor **121** is denoted as g in order to be distinguished from other nodes.

In the transistor **121**, the source node is connected to the power supply line **116**, and the drain node is respectively connected to the other of the source or the drain node of the transistor **123** and the source node of the transistor **124**. Here, the potential Vel which is the high order side of the power in the pixel circuit **110** is supplied to the power supply



line 116. The transistor 121 functions as a driving transistor driving current according to the voltage between the gate node and the source node of the transistor 121.

The control signal  $G_{cmp}(i)$  is supplied to the gate node of the transistor 123. The transistor 123 controls the electrical connection between the source node and the gate node  $g$  of the transistor 121 and functions as a threshold compensation transistor.

The control signal  $G_{el}(i)$  is supplied to the gate node of the transistor 124 and the drain node is respectively connected to the source node of the transistor 125 and the anode 130a of the OLED 130. In other words, the transistor 124 controls the electrical connection between the drain node of the transistor 121 and the anode 130a and functions as a light-emitting control transistor.

The control signal  $G_{orst}(i)$  corresponding to the  $i$  row is supplied to the gate node of the transistor 125, and the drain node is connected to the potential line 16 of the  $(3j-1)$ -th column and preserved at the potential  $V_{orst}$ . The transistor 125 functions as an initialization transistor controlling the electrical connection between the potential line 16 and the anode 130a.

The other end of the storage capacitor 132 is connected to the power supply line 116. For this reason, the storage capacitor 132 functions as a first storage capacitor holding the voltage between the gate and the source of the transistor 121. In the following, the capacitance of the storage capacitor 132 is denoted as  $C_{pix}$ .

Here, the capacitance  $C_{dt}$  of the storage capacitor 50, the capacitance  $C_{rfl}$  of the storage capacitor 44, and the capacitance  $C_{pix}$  of the storage capacitor 132 are set so that  $C_{dt} > C_{rfl} \gg C_{pix}$ .

That is,  $C_{dt}$  is set to be greater than  $C_{rfl}$ , and  $C_{pix}$  is set to be sufficiently smaller than  $C_{dt}$  and  $C_{rfl}$ .

Since the electro-optical device 10 in the present embodiment is formed on a silicon substrate, the substrate potential of the transistors 121 to 125 is set to the potential  $V_{el}$ .

The anode 130a of the OLED 130 is a pixel electrode provided individually for each pixel circuit 110. In contrast, the cathode of the OLED 130 is a common electrode 118 common across all of the pixel circuits 110, and preserved at the potential  $V_{ct}$  which is the low order side of the power in the pixel circuits 110.

In the above-described silicon substrate, the OLED 130 is an element in which a white organic EL layer is interposed by an anode and a cathode having light permeability. Here, on the output side (cathode side) of the OLED 130, a color filter corresponding to any one of RGB is superimposed.

In such an OLED 130, when the current flows from the anode to the cathode, the holes injected from the anode and the electrons injected from the cathode are recombined in the organic EL layer, excitons are produced, and white light is generated. The white light generated at this time passes through a cathode of the opposite side to the silicon substrate (anode), is colored by the color filter, and configured to be visible on the observation side.

Description will be given of the structure of the pixel circuits 110 with reference to FIG. 4 and FIG. 5.

FIG. 4 is a plan view showing a configuration of four mutually adjacent pixel circuits 110 in the vertical and horizontal directions. In addition, FIG. 5 is a partial cross-sectional view cut away along line VA-VA in FIG. 4.

In addition, FIG. 4 shows the wiring structure of a case where the pixel circuit 110 of the transmission structure is a plan view from the observation side; however, for simplicity, the structural body formed after the second wiring layer to be described later has been omitted. Further, in FIG. 5, for

simplicity, the structural body formed after the anode 130a in the OLED 130 has been omitted.

Here, in each of the above drawings, there are cases where the scales are made to be different in order to set each layer, each member, each region, and the like to a visible size.

As shown in FIG. 5, each element configuring the pixel circuit 110 is formed on a silicon substrate 150. In the present embodiment, a P type semiconductor substrate is used as the silicon substrate 150.

On the silicon substrate 150, N wells 160 are formed across almost the entire surface. Here, in FIG. 4, when shown in plan view, in order to enable the regions where the transistors 121 to 125 are provided to be easily grasped, only the regions where the transistors 121 to 125 are provided and the vicinity thereof in the N wells 160 are shown with hatching.

A potential  $V_{el}$  is supplied to the N wells 160 through an N type diffusion layer (not shown). For this reason, the substrate potential of the transistors 121 to 125 is the potential  $V_{el}$ .

As shown in FIG. 4 and FIG. 5, by doping ions in the surface of the N wells 160, a plurality of P type diffusion layers are formed. Specifically, on the surface of the N wells 160, 8 P type diffusion layers P1 to P8 are formed for each pixel circuit 110.

These P type diffusion layers P1 to P8 function as sources or drains of the transistors 121 to 125.

As shown in FIG. 5, on the surfaces of the N wells 160 and the P type diffusion layers P1 to P8, a gate insulating layer L0 and gate electrodes G1 to G5 are formed by patterning.

These gate electrodes G1 to G5 function as gates of each of the transistors 121 to 125.

As is shown in FIG. 4 and FIG. 5, the transistor 121 is configured to have a gate electrode G1, a P type diffusion layer P7 and a P type diffusion layer P8. Among these, the P type diffusion layer P8 functions as a source of the transistor 121, and the P type diffusion layer P7 functions as a drain of the transistor 121.

In addition, the transistor 122 is configured to have a gate electrode G2, a P type diffusion layer P1 and a P type diffusion layer P2. Among these, the P type diffusion layer P1 functions as one of a source or a drain of the transistor 122, and the P type diffusion layer P2 functions as the other of the source or the drain of the transistor 122.

The transistor 123 is configured to have a gate electrode G3, a P type diffusion layer P2 and a P type diffusion layer P3. Among these, the P type diffusion layer P2 functions as one of a source or a drain of the transistor 123 and the P type diffusion layer P3 functions as the other of the source or the drain of the transistor 123.

The transistor 124 is configured to have a gate electrode G4, a P type diffusion layer P3 and a P type diffusion layer P4. Among these, the P type diffusion layer P3 functions as a source of the transistor 124, and the P type diffusion layer P4 functions as a drain of the transistor 124.

The transistor 125 is configured to have a gate electrode G5, a P type diffusion layer P5 and a P type diffusion layer P6. Among these, the P type diffusion layer P5 functions as a source of the transistor 125, and the P type diffusion layer P6 functions as a drain of the transistor 125.

As shown in FIG. 4, when viewed in plan view, there is a region in which a part of the gate electrode G1 and a part of a P type diffusion layer P8 are overlapped. The storage capacitor 132 is configured by the interposition of a gate insulating layer L0 by a portion corresponding to the over-



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lapping region in the gate electrodes G1 and the portion corresponding to the overlapping region in the P type diffusion layer P8.

As shown in FIG. 5, a first interlayer insulating layer L1 is formed so as to cover the gate electrodes G1 to G5 and the gate insulating layer L0.

By patterning a wiring layer with conductivity of aluminum or the like on the surface of the first interlayer insulating layer L1, scanning lines 12, power supply lines 116, and signal lines 141 to 143 are respectively formed and relay nodes N1 to N6 are respectively formed for each pixel circuit 110. Here, there are cases where these wiring layers formed on the surface of the first interlayer insulating layer L1 are collectively referred to as first wiring layers.

As shown in FIG. 4 and FIG. 5, the relay node N1 is connected to the P type diffusion layer P1 through a contact hole Ha1 passing through the first interlayer insulating layer L1. In other words, the relay node N1 is equivalent to one of the source node or the drain node of the transistor 122. Here, in FIG. 4, the contact holes are shown as portions having a square mark with a cross inside at portions where different types of wiring layers are overlapped.

The relay node N2 is connected to the P type diffusion layer P2 through the contact hole Ha2 and connected to the gate electrode G1 through the contact hole Ha11. In other words, the relay node N2 is equivalent to the gate node g of the transistor 121, and equivalent to the other of the source node or the drain node of the transistor 122 and one of the source or drain node of the transistor 123.

The relay node N3 is connected to the P type diffusion layer P3 through the contact hole Ha3 and connected to the P type diffusion layer P7 through the contact hole Ha7. In other words, the relay node N3 is equivalent to the drain node of the transistor 121, and equivalent to the other of the source or the drain node of the transistor 123 and the source node of the transistor 124.

The relay node N4 is connected to the P type diffusion layer P4 through the contact hole Ha4 and connected to the P type diffusion layer P5 through the contact hole Ha5. In other words, the relay node N4 is equivalent to the drain node of the transistor 124, and equivalent to the source node of the transistor 125.

The relay node N5 is connected to the P type diffusion layer P6 through the contact hole Ha6. In other words, the relay node N5 is equivalent to the drain node of the transistor 125.

The relay node N6 is connected to the P type diffusion layer P8 through a contact hole Ha8. That is, the relay node N6 is equivalent to the source node of the transistor 121.

The signal line 141 is connected to the gate electrode G4 through a contact hole Ha4. Here, a control signal Gel(i) corresponding to the pixel circuit 110 is supplied to the signal line 141.

The signal line 142 is connected to the gate electrode G5 through a contact hole Ha5. Here, a control signal Gorst(i) corresponding to the pixel circuit 110 is supplied to the signal line 142.

The signal lines 143 are connected to the gate electrode G3 through a contact hole Ha3. Here, the control signal Gcmp(i) corresponding to the pixel circuits 110 is supplied to the signal lines 143.

The scanning line 12 is connected to the gate electrode G2 through a contact hole Ha2. The power supply line 116 is connected to the P type diffusion layer P8 through a contact hole Ha9.

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Here, the contact holes Ha2 to Ha9 and the contact holes Ha11 to Ha15 are contact holes passing through the first interlayer insulating layer L1.

As shown in FIG. 5, the second interlayer insulating layer L2 is formed so as to cover the first wiring layer and the first interlayer insulating layer L1.

By patterning a conductive wiring layer of aluminum or the like on the surface of the second interlayer insulating layer L2, the data lines 14 and the potential lines 16 are respectively formed and, for each pixel circuit 110, the relay node N11 and the relay node N12 are respectively formed. Here, there are cases where the wiring layers formed on the surface of these second interlayer insulating layers L2 are collectively referred to as second wiring layers.

As shown in FIG. 4, the relay node N11 is connected to the relay node N4 through the contact hole Hb2.

The relay node N12 is connected to the relay node N6 through the contact hole Hb4 and connected to the power supply line 116 through the contact hole Hb5. For this reason, the power supply line 116 is connected to the P type diffusion layer P8 (that is, the source of the transistor 121) through the relay node N12 and relay node N6.

The data lines 14 are connected to the relay node N1 through the contact hole Hb1. For this reason, the data lines 14 are connected to the P type diffusion layer P1 through the relay node N1 (that is, one of the source or the drain of the transistor 122).

The potential line 16 is connected to the relay node N5 through the contact hole Hb3. For this reason, the potential line 16 is connected to the P type diffusion layer P6 (that is, the drain of the transistor 125) through the relay node N5. In addition, the contact holes Hb1 to Hb5 are contact holes passing through the second interlayer insulating layer L2.

As shown in FIG. 5, the third interlayer insulating layer L3 is formed so as to cover the second wiring layer and the second interlayer insulating layer L2.

In this manner, the data lines 14 and potential lines 16 which are formed in the same layer (second wiring layer) adjacent to each other interpose the third interlayer insulating layer L3. As a result, the data lines 14 and potential lines 16 which are adjacent to each other are capacitively coupled, and a storage capacitor 50 is formed between the two. The data lines 14 and potential lines 16 extending in the Y direction from the upper part to the lower part of the display unit 100 have a length equivalent to one side of the display unit 100, as shown in FIG. 2. Accordingly, it is possible to set the capacitance Cdt of the storage capacitor 50 to a large value. Further, since the storage capacitor 50 is formed using the data lines 14 and potential lines 16 which are adjacent to each other, it is not necessary to make new space, and it is possible to provide a large capacitance Cdt.

As shown in FIG. 5, by patterning a conductive wiring layer of aluminum or the like on the surface of the third interlayer insulating layer L3, a relay node N21 is formed at each pixel circuit 110 and a power supply layer 116a is continuously formed across the region corresponding to the display unit 100. The power supply layer 116a is formed from a conductive metal having a light reflecting property. Here, there are cases where the wiring layers formed on the surface of the third interlayer insulating layer L3 are collectively referred to as third wiring layers.

The relay node N21 is connected to the relay node N11 through the contact hole Hc1 passing through the third interlayer insulating layer L3.

Further, although omitted from the drawings, the power supply layer 116a is electrically connected to the power supply line 116.



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As shown in FIG. 5, a fourth interlayer insulating layer L4 is formed so as to cover the third wiring layers and the third interlayer insulating layer L3.

The anode 130a of the OLED 130 is formed on the fourth interlayer insulating layer L4 by patterning a wiring layer having conductivity of aluminum, ITO (Indium Tin Oxide), or the like.

These anodes 130a are individual pixel electrodes for each pixel circuit 110, and are connected to the relay node n21 through a contact hole Hd1 passing through the fourth interlayer insulating layer L4. That is, the anodes 130a are connected to the P type diffusion layer P4 (in other words, the drain of the transistor 124) and the P type diffusion layer P5 (in other words, the source of the transistor 125) through the relay node N21, the relay node N11 and the relay node N4.

In the electro-optical device 10, the structure after the anodes 130a is omitted from the drawing; however, a light-emitting layer formed of an organic EL material divided for each pixel circuit 110 is laminated on the anodes 130a. Here, a cathode (common electrode 118) which is a common transparent electrode is provided across all of the plurality of pixel circuits 110 on the light-emitting layer.

That is, the OLED 130 interposes the light-emitting layer between the anode 130a and the common electrode 118 opposite to each other, and emits light with a luminance according to the current flowing toward the common electrode 118 from the anode 130a. In the light emitted from the OLED 130, the light in the direction opposite (that is, the upward direction in FIG. 5) to the silicon substrate 150 is visible to an observer as an image (top emission structure).

In addition to this, a sealing material or the like for sealing the light-emitting layer from the atmosphere is provided; however, description thereof is omitted.

Here, as described above, since the power supply layer 116a is formed so as to cover approximately the whole surface of the display unit 100, almost all of the light toward the silicon substrate 150 in the light emitted from the OLED 130 is irradiated in a direction opposite to the silicon substrate 150. Accordingly, the electro-optical device 10 according to the present embodiment is capable of increasing the use efficiency of the light and reducing the power consumption. Further, since the light emitted from the OLED 130 is blocked by the power supply layer 116a, it is possible to protect the wiring layers, the transistors 121 to 125, and the like, which are formed closer to the silicon substrate 150 side than the third interlayer insulating layer L3, from the light.

In the present embodiment, the contact hole Ha8 and the contact hole Hb4 are provided at different positions when viewed in plan view; however, they may be provided so as to overlap with each other when viewed in plan view. Similarly, the contact hole Hag and the contact hole Hb5 may also be provided so as to overlap with each other when viewed in plan view. Further, the contact hole Ha4 and the contact hole Hb2 may also be provided so as to overlap with each other when viewed in plan view.

Further, in the present embodiment, the storage capacitor 132 is configured by interposing the gate insulating layer L0 with the gate electrode G1 and the P type diffusion layer P8; however, it may be formed by interposing the insulating layer with wiring layers which are different to each other. For example, the storage capacitor 132 may be formed by interposing the second interlayer insulating layer L2 with the first wiring layer and the second wiring layer.

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## Operation of the First Embodiment

Description will be given of the operation of the electro-optical device 10 with reference to FIG. 6. FIG. 6 is a timing chart for illustrating operations of each portion in the electro-optical device 10.

As shown in the drawing, the scanning signals Gwr(1) to Gwr(m) are sequentially switched to the L level and, in the period of one frame, the first to the m-th rows of scanning lines 12 are scanned in order for each single horizontal scanning period (H).

The operation in the single horizontal scanning period (H) is common across the pixel circuits 110 of each row. In the following, description will be given of the operation in a scanning period in which an i-th row is horizontally scanned with particular focus on the pixel circuit 110 of the i row (3j-2) column.

In the present embodiment, when classifying the scanning periods of the i-th row, in FIG. 6, the periods are divided into an initialization period shown by (b), a compensation period shown by (c), and a writing period shown by (d). Here, after the writing period of (d), after a pause, a light-emitting period shown by (a) is started, and the scanning period of the i-th row is reached again after the passing of the period of one frame. For this reason, regarding the chronological order, a cycle of (light-emitting period)→initialization period→compensation period→writing period→(light-emitting period) is repeated.

Here, in FIG. 6, each of the scanning signal Gwr(i-1), the control signals Gel(i-1), Gcmp(i-1) and Gorst(i-1) corresponding to the (i-1)-th row one row before the i row forms a waveform which is earlier than each of the scanning signal Gwr(i), and the control signals Gel(i), Gcmp(i) and Gorst(i) corresponding to the i row by a single horizontal scanning period (H) only.

## Light-Emitting Period

For convenience of explanation, description will be given from the light-emitting period which is a prerequisite for the initialization period. As shown in FIG. 6, in the light-emitting period of the i-th row, the scanning signal Gwr(i) is the H level and the control signal Gel(i) is the L level. In addition, among the control signals Gel(i), Gcmp(i), and Gorst(i) which are logic signals, the control signal Gel(i) is the L level, and the control signals Gcmp(i) and Gorst(i) are the H level.

For this reason, in the pixel circuits 110 of the i row (3j-2) column as shown in FIG. 7, the transistor 124 is turned on while the transistors 122, 123, and 125 are turned off. Therefore, the transistor 121 supplies a current Ids according to the voltage Vgs between the gate and the source to the OLED 130. As will be described later, the Vgs voltage in the light-emitting period in the present embodiment is a value level-shifted according to the potential of the data signals from the threshold voltage of the transistor 121. For this reason, in the OLED 130, the current according to the gradation level is supplied in a state where the threshold voltage of the transistor 121 is compensated.

In addition, since the light-emitting period of the i-th row is a period in which horizontal scanning of other than the i-th row is performed, the potential of the data lines 14 is appropriately changed. However, in the pixel circuit 110 of the i-th row, since the transistor 122 is turned off, here, potential changes of the data lines 14 are not considered.



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In addition, in FIG. 7, the path which is important in the description of the operation is shown with a bold line (the same applies in FIGS. 8 to 10, and FIGS. 15 to 18 below).  
Initialization Period

Next, when the scanning period of the  $i$ -th row is reached, first, the initialization period of (b) is started as the first period. In the initialization period, in comparison with the light-emitting period, the control signal  $G_{el}(i)$  is changed to the H level and the control signal  $G_{orst}(i)$  is changed to the L level, respectively.

For this reason, as shown in FIG. 8, in the pixel circuit 110 of the  $i$  row ( $3j-2$ ) column, the transistor 124 is turned off and the transistor 125 is turned on. In this manner, the path of the current supplied to the OLED 130 is interrupted and the anodes of the OLED 130 are reset to the potential  $V_{orst}$ .

Since the OLED 130 has a configuration in which the organic EL layer is interposed by the anode and the cathode as described above, as shown by a broken line in the drawing, a capacitor  $C_{oled}$  has a parasitic effect in parallel between the anode and the cathode. When the current was flowing in OLED 130 in the light-emitting period, the voltages of both ends between the anode and the cathode of the OLED 130 are held by the capacitor  $C_{oled}$ ; however, the held voltage is reset by turning on the transistor 125. For this reason, in the present embodiment, when the current flows again to the OLED 130 in the subsequent light-emitting period, it is not easily affected by the influence of the voltage held by the capacitor  $C_{oled}$ .

In detail, for example, when a high luminance display state is changed to a low luminance display state, if the configuration is one which is not reset, since a high voltage of the time when the luminance was high (a large current was flowing) is held, next, an excessive current is made to flow when trying to make a small current flow and it becomes impossible to obtain the low luminance display state. In contrast, in the present embodiment, since the potential of the anode of the OLED 130 is reset by turning the transistor 125 on, the reproducibility of the low luminance side can be improved.

In this embodiment, regarding the potential  $V_{orst}$ , the difference between the potential  $V_{orst}$  and the potential  $V_{ct}$  of the common electrode 118 is set so as to fall below the light-emitting threshold voltage of the OLED 130. For this reason, in the initialization period (the compensation period and writing period described next), the OLED 130 is in an off (non-light-emitting) state.

On the other hand, in the initialization period, since the control signal  $/G_{ini}$  is the L level and the Control signal  $G_{ref}$  is the H level, the transistors 45 and 43 as shown in FIG. 8 are respectively turned on in the level shift circuit 40. For this reason, the data line 14 which is one end of the storage capacitor 44 is initialized to the potential  $V_{ini}$  and the node  $h$  which is the other end of the storage capacitor 44 is initialized to the potential  $V_{ref}$ , respectively.

Regarding the potential  $V_{ini}$  in the present embodiment,  $(V_{el}-V_{ini})$  is set to be larger than the threshold voltage  $|V_{th}|$  of the transistor 121. In addition, since the transistor 121 is a P channel type, the threshold voltage  $V_{th}$  based on the potential of the source node is negative. Here, in order to prevent confusion in the description of the relationship between high and low, the threshold voltage is set to be expressed by the absolute value  $|V_{th}|$  and regulated by magnitude correlation.

In addition, with respect to the potential which can be taken by the data signals  $V_d(1)$  to  $V_d(n)$ , the potential  $V_{ref}$  in the present embodiment is set to a value such that the

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potential of the node  $h$  in the subsequent writing period is increased, for example, set to be lower than the minimum value  $V_{min}$ .

Compensation Period

In the scanning period of the  $i$ -th row, next, the compensation period of (c) is the second period. In the compensation period, in comparison with the initialization period, the scanning signal  $G_{wr}(i)$  and the control signal  $G_{cmp}(i)$  are the L level. Meanwhile, in the compensation period, the control signal  $/G_{ini}$  is the H level in a state where the control signal  $G_{ref}$  is maintained at the H level.

For this reason, as shown in FIG. 9, in the level shift circuit 40, the node  $h$  is fixed at the potential  $V_{ref}$  by turning off the transistor 45 in a state where the transistor 43 is turned on. Meanwhile, since the gate node  $g$  is electrically connected to the data lines 14 by turning on the transistor 122 in the pixel circuit 110 of the  $i$  row ( $3j-2$ ) column, the gate node  $g$  becomes the potential  $V_{ini}$  at the start of the compensation period.

Since the transistor 123 is turned on in the compensation period, the transistor 121 becomes a diode connection. For this reason, the drain current flows in the transistor 121 and charges the gate node  $g$  and the data lines 14. In detail, the current flows in a path of the power supply line 116→the transistor 121→transistor 123→the transistor 122→the data line 14 of the ( $3j-2$ )-th column. For this reason, the data lines 14 and the gate node  $g$  which are in a mutually connected state due to the turning on of the transistor 121 are increased from the potential  $V_{ini}$ .

However, since the current flowing in the above path flows less easily as the gate node  $g$  approaches the potential  $(V_{el}-|V_{th}|)$ , the data line 14 and the gate node  $g$  are saturated by the potential  $(V_{el}-|V_{th}|)$  until the end of the compensation period is reached. Accordingly, the storage capacitor 132 holds the threshold voltage  $|V_{th}|$  of the transistor 121 until the end of the compensation period is reached.

Writing Period

After the initialization period, the writing period of (d) as the third period is reached. In the writing period, since the control signal  $G_{cmp}(i)$  becomes the H level, the diode connection of the transistor 121 is canceled, while since the control signal  $G_{ref}$  becomes the L level, the transistor 43 is turned off. For this reason, the path from the data line 14 of the ( $3j-2$ )-th column to the gate node  $g$  in the pixel circuit 110 of the  $i$  row ( $3j-2$ ) column is in a floating state, but the potential in the path is maintained at  $(V_{el}-|V_{th}|)$  by the storage capacitors 50 and 132.

For a  $j$ -numbered group, the control circuit 5 in the writing period of the  $i$  row switches the data signals  $V_d(j)$  in order to a potential according to the gradation level of pixels of the  $i$  row ( $3j-2$ ) column, the  $i$  row ( $3j-1$ ) column, and the  $i$  row ( $3j$ ) column. Meanwhile, the control circuit 5 sets the control signals  $Sel(1)$ ,  $Sel(2)$ , and  $Sel(3)$  in order exclusively to the H level in accordance with the switching of the potential of the data signal. The control circuit 5 has been omitted in FIG. 6; however, output is also performed for the control signals  $/Sel(1)$ ,  $/Sel(2)$ , and  $/Sel(3)$  which have an inverse logic relationship with the control signals  $Sel(1)$ ,  $Sel(2)$ , and  $Sel(3)$ . In this manner, in the demultiplexer 30, the transmission gates 34 in each group are turned on in order of the left end column, the center column, and the right end column, respectively.

Here, when the transmission gate 34 of the left end column is turned on by the control signals  $Sel(1)$ , and  $/Sel(1)$ , as shown in FIG. 10, the node  $h$  which is the other end of the storage capacitor 44 is changed from the



potential  $V_{ref}$  fixed in the initialization period and the compensation period to the potential of the data signal  $V_d(j)$ , that is, to a potential according to the gradation level of pixels of the  $i$  row ( $3j-2$ ) column. The potential change amount of the node  $h$  at this time is set as  $\Delta V$  and the potential after the change is set to be expressed as  $(V_{ref} + \Delta V)$ .

Meanwhile, since the gate node  $g$  is connected to one end of the storage capacitor **44** through the data lines **14**, it has a value  $(V_{el} - |V_{th}| + k_1 \cdot \Delta V)$  shifted upwards from the potential  $(V_{el} - |V_{th}|)$  in the compensation period by a value in which the potential change amount  $\Delta V$  of the node  $h$  is multiplied by the capacitance ratio  $k_1$  only. At this time, the voltage  $V_{gs}$  of the transistor **121** becomes a value  $(|V_{th}| - k_1 \cdot \Delta V)$  in which the shifting amount of the increased potential of the gate node  $g$  only is subtracted from the threshold voltage  $|V_{th}|$ .

Here, the capacitance ratio  $k_1$  is  $C_{rf1}/(C_{dt} + C_{rf1})$ . Strictly speaking, the capacitance  $C_{pix}$  of the storage capacitor **132** must also be considered; however, since the capacitance  $C_{pix}$  is set so as to become sufficiently small in comparison with the capacities  $C_{rf1}$  and  $C_{dt}$ , it has been ignored.

FIG. **11** is a view showing the relationship between the potential of the data signal and the potential of the gate node  $g$  in the writing period. The data signal supplied from the control circuit **5** can take a potential range of from the minimum value  $V_{min}$  to the maximum value  $V_{max}$  according to the gradation level of the pixels as described above. In the present embodiment, the data signals are not written directly to the gate node  $g$ , but are level-shifted as shown in the drawing and written to the gate node  $g$ .

At this time, the potential range  $\Delta V_{gate}$  of the gate node  $g$  is compressed to a value in which the potential range  $\Delta V_{data}$  ( $=V_{max} - V_{min}$ ) of the data signal is multiplied by the capacitance ratio  $k_1$ . For example, when the capacities of the storage capacitors **44** and **50** are set so that  $C_{rf1}:C_{dt}=1:9$ , it is possible to compress the potential range  $\Delta V_{gate}$  of the gate node  $g$  to  $1/10$  of the potential range  $\Delta V_{data}$  of the data signal.

In addition, regarding in which direction and to what extent the potential range  $\Delta V_{gate}$  of the gate node  $g$  is shifted with respect to the potential range  $\Delta V_{data}$  of the data signal, determination can be made with the potential  $V_p$  ( $V_{el} - |V_{th}|$ ), and  $V_{ref}$ . This is because the potential range  $\Delta V_{data}$  of the data signal is compressed by the capacitance ratio  $k_1$  based on the potential  $V_{ref}$  and one in which the compression range is shifted based on the potential  $V_p$  becomes the potential range  $\Delta V_{gate}$  of the gate node  $g$ .

In the writing period of such an  $i$ -th row, a potential  $(V_{el} - |V_{th}| + k_1 \cdot \Delta V)$  shifted from a potential  $(V_{el} - |V_{th}|)$  in the compensation period by an amount in which the potential change amount  $\Delta V$  of the node  $h$  is multiplied by the capacitance ratio  $k_1$  is written to the gate node  $g$  of the pixel circuit **110** of the  $i$ -th row.

Eventually, the scanning signal  $G_{wr}(i)$  becomes the H level and the transistor **122** is turned off. In this manner, the writing period is finished and the potential of the gate node  $g$  is confirmed at the shifted value.

#### Light-Emitting Period

After the writing period of the  $i$ -th row is finished, the light-emitting period is reached during the single horizontal scanning period. In this light-emitting period, since the control signal  $G_{el}(i)$  as described above becomes the L level, the transistors **124** in the pixel circuits **110** of the  $i$  row ( $3j-2$ ) columns are turned on. Since the voltage  $V_{gs}$  between the gate and the source is  $(|V_{th}| - k_1 \cdot \Delta V)$ , as shown in the previous FIG. **7**, the current according to the gradation level

is supplied to the OLED **130** in a state where the threshold voltage of the transistor **121** is compensated.

Such an operation is performed in parallel in terms of time in the scanning period of the  $i$ -th row and the also in the other pixel circuits **110** of the  $i$ -th row other than the pixel circuits **110** of the  $(3j-2)$ -th column. In addition, such an operation of the  $i$ -th row is in practice performed in the order of 1, 2, 3, . . . ,  $(m-1)$ , and  $m$ -th row in the period of one frame, and is repeated for each frame.

#### Effect of the First Embodiment

Since the storage capacitor **50** is formed by interposing the third interlayer insulating layer **L3** with the data lines **14** and the potential lines **16** having lengths equivalent to one side of the display unit **100**, it is possible to set the capacitance  $C_{dt}$  of the storage capacitor **50** to a large value. The capacitance  $C_{dt}$  is sufficiently large in comparison with the capacitance  $C_{pix}$  of the storage capacitor **132** formed inside the pixel circuit **110** and, moreover, is large in comparison with the capacitance  $C_{rf1}$  of the storage capacitor **44** formed in the region limited by the outside of the display unit **100**. Accordingly, it is possible to set the capacitance ratio  $k_1$  of the capacitance  $C_{dt}$  and the capacitance  $C_{rf1}$  to a small value.

That is, according to the present embodiment, by setting the capacitance ratio  $k_1$  to a small value, it is possible to compress the potential range  $\Delta V_{gate}$  in the gate node  $g$  to a sufficiently small value with respect to the potential range  $\Delta V_{data}$  of the data signals. In this manner, even without cutting up the data signals with fine precision, it is possible to apply a voltage reflecting the gradation level between the gate and source of the transistor **121**. Thus, even in a case where a micro current flowing in the OLED **130** with respect to changes in the voltage  $V_{gs}$  between the gate and source of the transistor **121** in the miniature pixel circuit **110** is changed to a relatively large extent, it is possible to control the current supplied to the OLED **130** with good precision.

According to the present embodiment, the storage capacitor **50** is formed by data lines **14** and potential lines **16** having lengths equivalent to sides of the display unit **100**. That is, the capacitance  $C_{dt}$  of the storage capacitor **50** is formed by electrodes having a large area. The variation of each column of the storage capacitor **50** depends on the errors in the semiconductor processing; however, by forming the storage capacitor **50** using an electrode with a large area, it is possible to reduce the relative variation of the capacitance  $C_{dt}$  of the storage capacitor **50**.

Accordingly, if it is possible to suppress the variation of each column of the capacitance  $C_{rf1}$  of the storage capacitor **44** to be small, it is also possible to suppress the variation of each column for the capacitance ratio  $k_1$  of capacitance  $C_{dt}$  and capacitance  $C_{rf1}$ . In this manner, it is possible to suppress the generation of luminance unevenness caused by variation in the capacitance ratio  $k_1$ .

Further, each of the storage capacitors **50** provided in each column is provided in common to  $m$  pixel circuits **110** connected to each data line **14**. For this reason, it is possible to provide a large capacitance in each pixel circuit **110** without forming a large storage capacitance inside the pixel circuits **110**, and it is possible to achieve both miniaturization of the pixel circuits **110** and improvement of the display quality.

Here, in the writing period, in a case where the data signal  $V_d(j)$  is supplied to the other end of the storage capacitor **44**, charge transfer is generated from one end of the storage capacitor **44** with respect to the storage capacitor **132** and the storage capacitor **50**. That is, the present embodiment determines the potential of the gate node  $g$  by distributing a



charge supplied from one end of the storage capacitor **44** in the writing period to the storage capacitor **132** and the storage capacitor **50**.

More specifically, the charge supplied from one end of the storage capacitor **44** in the writing period is distributed to the storage capacitor **50** and the storage capacitor **132** according to the capacitance ratio of the storage capacitor **50** and the storage capacitor **132**. Thus, the potential change amount of the gate node *g* in the writing period is determined based on the capacitance  $C_{dt}$  of the storage capacitor **50** and the charge distributed to the storage capacitor **50** and the capacitance  $C_{pix}$  of the storage capacitor **132** and the charge distributed to the storage capacitor **132**. Since the capacitance  $C_{dt}$  of the storage capacitor **50** is sufficiently large in comparison with the capacitance  $C_{pix}$  of the storage capacitor **132**, the potential change amount of the gate node *g* in the writing period is substantially determined according to the capacitance  $C_{dt}$  of the storage capacitor **50** and the charge distributed to the storage capacitor **50**. As described above, the variation in the capacitance  $C_{dt}$  for each column is small. Accordingly, according to the present embodiment, it is possible to suppress the variation for each column of the potential change amount of the gate node *g* in the writing period.

In contrast, even if the electro-optical device **10** is not provided with a storage capacitor **50**, the charge supplied from one end of the storage capacitor **44** in the writing period is held by the storage capacitor **132**. In other words, in a case where the electro-optical device **10** is not provided with a storage capacitor **50**, the potential change amount of the gate node *g* in the writing period is determined by the charge supplied from one end of the storage capacitor **44** in the writing period and the capacitance  $C_{pix}$  of the storage capacitor **132**. Since the storage capacitor **132** is formed inside the miniature pixel circuit **110**, the relative variation of the capacitance  $C_{pix}$  is large in comparison with the relative variation of the capacitance  $C_{dt}$ . Accordingly, in such a case, the variation for each column of the potential change amount of the gate node *g* in the writing period becomes large.

In this manner, according to the present embodiment, since it is possible to reduce the relative variation of the potential change amount of the gate node *g* in the writing period by providing the storage capacitor **50**, it is possible to suppress the generation of luminance unevenness and to improve the display quality.

In addition, between the data lines **14** shown by a broken line in FIG. **3** and the gate node *g* in the pixel circuit **110** there is a parasitic capacitance  $C_{prs}$  in practice. For this reason, if the potential change range of the data line **14** is large, there is propagation to the gate node *g* through capacitance  $C_{prs}$ , whereby so-called cross-talk, non-uniformity, or the like is generated and the display quality is deteriorated. The influence of the capacitance  $C_{prs}$  is remarkably apparent when the pixel circuit **110** is miniaturized.

In contrast, in the present embodiment, since the potential change range of the data lines **14** is also narrowed with respect to the potential range  $\Delta V_{data}$  of the data signal, it is possible to suppress the influence through the capacitance  $C_{prs}$ .

According to the present embodiment, since it is possible to preserve a period which is longer than the scanning period, for example, 2 horizontal scanning periods, as the period in which the transistor **125** is turned on, that is, the reset period of the OLED **130**, it is possible to sufficiently

initialize the voltage held in the parasitic capacitance of the OLED **130** in the light-emitting period.

In addition, according to the present embodiment, in the current  $I_{ds}$  supplied to the OLED **130** by the transistor **121**, the influence of the threshold voltage is canceled out. For this reason, according to the present embodiment, even if the threshold voltage of the transistor **121** varies for each pixel circuit **110**, since the variations are compensated and the current according to the gradation level is supplied to the OLED **130**, the generation of display non-uniformity adversely affecting the uniformity of the display screen is suppressed and, as a result, a high-quality display is possible.

Description will be given of this cancelling out with reference to FIG. **12**. As shown in this drawing, in order to control the small current supplied to the OLED **130**, the transistor **121** operates in a weak inversion region (sub-threshold region).

In the drawing, A illustrates a transistor for which the threshold voltage  $|V_{th}|$  is large and B illustrates a transistor for which the threshold voltage  $|V_{th}|$  is small, respectively. Here, in FIG. **12**, the voltage  $V_{gs}$  between the gate and the source is the difference between the characteristic shown by the solid line and the potential  $V_{el}$ . Further, in FIG. **12**, the current of the vertical scale is shown by a logarithm in which the direction from the source toward the drain is set as positive (up).

The gate node *g* in the compensation period becomes a potential  $(V_{el} - |V_{th}|)$  from the potential  $V_{ini}$ . For this reason, for the transistor A in which the threshold voltage  $|V_{th}|$  is large, the operation point moves from S to Aa while, for the transistor B in which the threshold voltage  $|V_{th}|$  is small, the operation point moves from S to Ba.

Next, in a case where the potentials of the data signals to the pixel circuits **110** to which the two transistors belong are the same, that is, in a case where the same gradation level is indicated, in the writing period, the potential shift amounts from the operation points Aa and Ba are both the same  $k_1 \cdot \Delta$ . For this reason, for transistor A, the operation point moves from Aa to Ab, and for transistor B, the operation point moves from Ba to Bb; however, the currents at the operation points after the potential shift are aligned at almost the same  $I_{ds}$  for both the transistors A and B.

## Second Embodiment

In the first embodiment, a configuration is adopted in which data signals are directly supplied by the demultiplexer **30** to the other ends of the storage capacitors **44** of each column, that is, to the nodes *h*. For this reason, in the scanning period of each row, since the period in which the data signals are supplied by the control circuit **5** is equal to the writing period, the time constraints are large.

Here, description will be given of the second embodiment in which it is possible to relax such time constraints. Here, in the following, in order to avoid duplication of explanation, description will be given with a focus on the parts which are different to the first embodiment.

FIG. **13** is a view showing a configuration of an electro-optical device **10** according to the second embodiment.

The points where the second embodiment shown in the drawing is different to the first embodiment shown in FIG. **2** are mainly the points that a storage capacitor **41** and a transmission gate **42** are provided in each column of the level shift circuit **40**.

In detail, the transmission gates **42** in each column are electrically interposed between the output ends of the trans-



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mission gate **34** and the other ends of the storage capacitor **44**. That is, the input end of the transmission gate **42** is connected to the output end of the transmission gate **34**, and the output end of the transmission gate **42** is connected to the other end of the storage capacitor **44**. For this reason, the transmission gate **42** functions as a first switch.

Here, the transmission gates **42** of each column are turned on as a group when the control signal **Gcp1** supplied from the control circuit **5** is the H level (when the control signal **/Gcp1** is the L level).

On the other hand, the transmission gate **34** in the demultiplexer **30** functions as a second switch.

In addition, one end of the storage capacitors **41** in each column is connected to the output end of transmission gate **34** (input end of the transmission gate **42**), and the other end of the storage capacitors **41** is grounded in common at a fixed potential, for example, a potential **Vss**. Although omitted from FIG. **13**, the capacitance of the storage capacitor **41** is set as **Crf2**. Here, the potential **Vss** is equivalent to the L level of the scanning signals or control signals, which are logic signals.

## Operation of the Second Embodiment

Description will be given of the operation of the electro-optical device **10** according to the second embodiment with reference to FIG. **14**. FIG. **14** is a timing chart for illustrating the operation of the second embodiment.

As shown in the drawing, the point that the scanning signals **Gwr(1)** to **Gwr(m)** are sequentially switched to the L level and, in the period of one frame, the first to the m-th rows of scanning lines **12** are scanned in order for each single horizontal scanning period (H), is the same as the first embodiment. Further, in the second embodiment, the point that the scanning period of the i-th row follows the order of an initialization period shown by (b), a compensation period shown by (c), and a writing period shown by (d) is also the same as the first embodiment. Here, the writing period of (d) in the second embodiment is a period from the time the control signal **Gcp1** changes from the L to the H level (time when the control signal **/Gcp1** has become the L level) to the time when the scanning signal changes from the L to the H level.

In the second embodiment, similarly to the first embodiment, regarding the chronological order, a cycle of (light-emitting period)→initialization period→compensation period→writing period→(light-emitting period) is repeated. However, in the second embodiment, in comparison with the first embodiment, the supply period of the data signal is not equal to the writing period, and there is a difference in the point that the supply of the data signal precedes the writing period. In detail, the point that, in the second embodiment, the data signal can be supplied across the initialization period of (a) and the compensation period of (b) is different from the first embodiment.

## Light-Emitting Period

In the second embodiment, as shown in FIG. **14**, the scanning signal **Gwr(i)** in the light-emitting period of the i-th row is the H level, and, the control signal **Gel(i)** is the L level, and the control signals **Gcmp(i)** and **Gorst(i)** are the H level.

For this reason, in the pixel circuit **110** of i row (3j-2) column as shown in FIG. **15**, since the transistor **124** is turned on while the transistors **122**, **123**, and **125** are turned off, the operation of the pixel circuit **110** is basically the same as the first embodiment. In other words, the transistor

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**121** supplies a current **Ids** according to the voltage **Vgs** between the gate and the source to the OLED **130**.

## Initialization Period

Upon reaching the scanning period of the i-th row, first, the initialization period of (b) is started.

In the initialization period in the second embodiment, in comparison with the light-emitting period, the control signal **Gel(i)** is changed to the H level and the control signal **Gorst(i)** is changed to the L level, respectively.

For this reason, as shown in FIG. **16**, in the pixel circuit **110** of the i row (3j-2) column, the transistor **124** is turned off and the transistor **125** is turned on. In this manner, since the path of the current supplied to the OLED **130** is interrupted and the anodes of the OLED **130** are reset to the potential **Vorst** by the turning on of the transistor **124**, the operation of the pixel circuit **110** is basically the same as the first embodiment.

Meanwhile, in the initialization period in the second embodiment, the control signal **/Gini** becomes the L level, the control signal **Gref** becomes the H level, and the control signal **Gcp1** becomes the L level. For this reason, in the level shift circuit **40**, the transistors **45** and **43** are respectively turned on as shown in FIG. **16** and the transmission gate **42** is turned off. Accordingly, the data line **14** which is one end of the storage capacitor **44** is initialized to the potential **Vini** and the node h which is the other end of the storage capacitor **44** is initialized to the potential **Vref**, respectively.

The potential **Vref** in the second embodiment is set to a value such that the potential of the node h in the subsequent writing period can be increased with respect to the potential which can be taken by the data signals **Vd(1)** to **Vd(n)**, similarly to the first embodiment.

As described above, the control circuit **5** in the second embodiment supplies data signals across the initialization period and the compensation period. That is, for a j-numbered group, the control circuit **5** switches the data signals **Vd(j)** in order to a potential according to the gradation level of pixels of the i row (3j-2) column, the i row (3j-1) column, and the i row (3j) column while setting the control signals **Sel(1)**, **Sel(2)**, and **Sel(3)** in order exclusively to the H level in accordance with the switching of the potential of the data signal. In this manner, in the demultiplexer **30**, the transmission gates **34** in each group are turned on in order of the left end column, the center column, and the right end column, respectively.

Here, in the initialization period, in a case where the transmission gate **34** of the left end side belonging to the j-numbered group is turned on by the control signal **Sel(1)**, as shown in FIG. **16**, since the data signal **Vd(j)** is supplied to one end of the storage capacitor **41**, the data signal is held by the storage capacitor **41**.

## Compensation Period

In the scanning period of the i-th row, the compensation period of (c) is next. In the compensation period in the second embodiment, in comparison with the initialization period, the scanning signal **Gwr(i)** is changed to the L level and the control signal **Gcmp(i)** is changed to the L level, respectively.

For this reason, as shown in FIG. **17**, the transistor **122** is turned on in the pixel circuit **110** of the i row (3j-2) column and the gate node g is electrically connected to the data lines **14**, while the transistor **121** becomes a diode connection due to the turning on of the transistor **123**.

Accordingly, since the current flows in the path of the power supply line **116**→transistor **121**→transistor **123**→transistor **122**→data line **14** of (3j-2)-th column, the gate node g is increased from the potential **Vini** and is



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eventually saturated at  $(V_{el}-|V_{th}|)$ . Accordingly, even in the second embodiment, the storage capacitor **132** holds the threshold voltage  $|V_{th}|$  of the transistor **121** until the end of the compensation period is reached.

In the second embodiment, since the control signal  $/G_{ini}$  becomes the H level in a state where the control signal  $G_{ref}$  is maintained at the H level in the compensation period, the node  $h$  in the level shift circuit **40** is fixed at a potential  $V_{ref}$ .

In addition, in the compensation period, in a case where the transmission gate **34** of the left end side belonging to the  $j$ -numbered group is turned on by the control signal  $Sel(1)$ , as shown in FIG. **17**, the data signal  $V_d(j)$  is held by the storage capacitor **41**.

Here, in the initialization period, in a case where the transmission gate **34** of the left end column belonging to the  $j$ -numbered group are already turned on by the control signal  $Sel(1)$ , in the compensation period, the transmission gate **34** is not turned on; however, there is no change in the point that the data signal  $V_d(j)$  is held by the storage capacitor **41**.

In addition, when the compensation period is finished, since the control signal  $G_{cmp}(i)$  is the H level, the diode connection of the transistor **121** is canceled.

In the second embodiment, since the control signal  $G_{ref}$  becomes the L level during the period from the end of the compensation period until the next writing period starts, the transistor **43** is turned off. For this reason, the path leading up to the gate node  $g$  in the pixel circuit **110** of  $i$  row  $(3j-2)$  column from the data line **14** of the  $(3j-2)$ -th column becomes a floating state, but the potential in the path is maintained at  $(V_{el}-|V_{th}|)$  by the storage capacitors **50** and **132**.

## Writing Period

In the writing period in the second embodiment, the control signal  $G_{cp1}$  becomes the H level (control signal  $/G_{cp1}$  becomes the L level). For this reason, as shown in FIG. **18**, since the transmission gate **42** is turned on in the level shift circuit **40**, the data signal held by the storage capacitor **41** is supplied to the node  $h$  which is the other end of the storage capacitor **44**. For this reason, the node  $h$  shifts from the potential  $V_{ref}$  in the compensation period. In other words, the node  $h$  is changed to the potential  $(V_{ref}+\Delta V)$ .

Meanwhile, since the gate node  $g$  is connected to one end of the storage capacitor **44** through the data lines **14**, it has a value shifted upwards from the potential  $(V_{el}-|V_{th}|)$  in the compensation period by a value in which the potential change amount  $\Delta V$  of the node  $h$  is multiplied by the capacitance ratio  $k_2$  only. In other words, the potential of the gate node  $g$  becomes a value  $(V_{el}-|V_{th}|+k_2\cdot\Delta)$  shifted upwards from the potential  $(V_{el}-|V_{th}|)$  in the compensation period by a value in which the potential change amount  $\Delta V$  of the node  $h$  is multiplied by the capacitance ratio  $k_2$  only.

Here, in the second embodiment, the capacitance ratio  $k_2$  is the capacitance ratio of  $C_{dt}$ ,  $C_{rf1}$ , and  $C_{rf2}$ . As described above, the capacitance  $C_{pix}$  of the storage capacitor **132** is ignored.

Further, at this time, the voltage  $V_{gs}$  of the transistor **121** becomes a value  $(|V_{th}|-k_2\cdot\Delta V)$  decreased by the amount which the potential of the gate node  $g$  shifts upward from the threshold voltage  $|V_{th}|$ .

## Light-Emitting Period

In the second embodiment, after the writing period of the  $i$ -th row is finished, the light-emitting period is reached during the single horizontal scanning period. In this light-emitting period, since the control signal  $G_{el}(i)$  as described above becomes the L level, the transistors **124** in the pixel circuits **110** of the  $i$  row  $(3j-2)$  columns are turned on.

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The voltage  $V_{gs}$  between the gate and the source is  $(|V_{th}|-k_2\cdot\Delta V)$  and is a value level-shifted according to the potential of the data signal from the threshold voltage of the transistor **121**. For this reason, as shown in the previous FIG. **15**, the current according to the gradation level is supplied to the OLED **130** in a state where the threshold voltage of the transistor **121** is compensated.

Such an operation is performed in parallel in terms of time in the scanning period of the  $i$ -th row and the also in the other pixel circuits **110** of the  $i$ -th row other than the pixel circuits **110** of the  $(3j-2)$ -th column. In addition, such an operation of the  $i$ -th row is in practice performed in the order of 1, 2, 3, . . . ,  $(m-1)$ , and  $m$ -th row in the period of one frame, and is repeated for each frame.

## Effect of the Second Embodiment

According to the second embodiment, similarly to the first embodiment, even in a case where a small current flowing through the OLED **130** with respect to changes of the voltage  $V_{gs}$  between the gate and the source of the transistor **121** in the fine pixel circuit **110** is changed to a relatively large extent, it is possible to control the current supplied to the OLED **130** with high precision.

According to the second embodiment, similarly to the first embodiment, as well as being able to sufficiently initialize the voltage held by the parasitic capacitance of the OLED **130** in the light-emitting period, even if the threshold voltage of the transistor **121** varies for each pixel circuit **110**, the generation of display non-uniformity adversely affecting the uniformity of the display screen is suppressed and, as a result, a high-quality display is possible.

According to the second embodiment, an operation of holding the data signal supplied through the demultiplexer **30** from the control circuit **5** in the storage capacitor **41** is performed from the initialization period to the compensation period. For this reason, it is possible to relax the time constraints on the operations to be performed in one horizontal scanning period.

For example, since, as the voltage  $V_{gs}$  between the gate and the source in the compensation period approaches the threshold voltage, the current flowing in the transistor **121** deteriorates, time is required to bring the gate node  $g$  to the potential  $(V_{el}-|V_{th}|)$ ; however, in the second embodiment, it is possible to preserve a long compensation period as shown in FIG. **14** in comparison with the first embodiment. For this reason, according to the second embodiment, in comparison with the first embodiment, it is possible to compensate the variations of the threshold voltage of the transistor **121** with high precision.

In addition, it is possible to slow down the supply operation of the data signal.

## Application and Modification Examples

The invention is not limited to embodiments such as the above-described embodiments and application examples, and, for example, various modifications are possible as described in the following. Further, one or a plurality of arbitrarily selected forms of the modifications described below can also be combined as appropriate.

## Control Circuit

In the embodiment described above, the control circuit **5** supplying data signals is set as separate to the electro-optical device **10**; however, the control circuit **5** may also be



integrated in the silicon substrate with the scanning line driving circuit **20**, the demultiplexer **30** and the level shift circuit **40**.

#### Substrate

In the above-described embodiments and modification examples, a configuration has been adopted in which the electro-optical device **10** is integrated in a silicon substrate; however, a configuration of integration with another semiconductor substrate may be adopted. Further, the device may be formed on a glass substrate or the like by applying polysilicon processing. In any case, the pixel circuits **110** are miniaturized and useful in a configuration in which the drain current is changed to exponentially increase with respect to changes in the gate voltage  $V_{gs}$  in the transistor **121**.

#### Demultiplexer

In the above-described embodiments and modification examples, a configuration is adopted in which the data lines **14** are grouped in threes, the data lines **14** are selected in order in each group, and data signals are supplied; however, the number of data lines configuring a group may be 2 or may be 4 or more.

In addition, a configuration may be adopted in which the data signals are supplied in line order together to the data lines **14** of each column without grouping, that is, without using the demultiplexer **30**.

#### Channel Type of Transistor

In the above-described embodiments and modification examples, the transistors **121** to **125** in the pixel circuits **110** are standardized as P channel types; however, they may be standardized as N channel types. Further, the P channel types and N channel types may be appropriately combined.

#### Storage Capacitor

In the above-described embodiments and modification examples, the potential of the gate node  $g$  and the data lines **14** was set through the storage capacitor **44** by supplying the data signal  $V_d(j)$  to the other end of the storage capacitor **44**; however, the invention is not limited to such a form, and the potential of the gate node  $g$  may be set by supplying the data signal  $V_d(j)$  directly to the other end of the data lines **14**. In such a case, the electro-optical device **10** need not be provided with the storage capacitor **44** (or the storage capacitor **41**).

#### Data Signal

In the above-described embodiments and modification examples, a potential according to the gradation level of the pixels is supplied as the data signal  $V_d(j)$ ; however, the invention is not limited to such a form.

For example, a current of a size according to the gradation level of the pixels may be supplied as the data signal. Further, a fixed current may be supplied for only a period of a length according to the gradation level of the pixels. In such cases, the current which is the data signal may be directly supplied to the data lines **14** without going through the storage capacitor **44**.

That is, the above-described embodiments and modification examples move a charge with respect to the storage capacitor **50** and the storage capacitor **132** from one end of the storage capacitor **44** and determine the potential of the gate node  $g$  by setting other end of the storage capacitor **44** to the potential of the data signal  $V_d(j)$ ; however, the present modification example determines the potential of the gate node  $g$  by supplying, to the storage capacitor **50** and the storage capacitor **132**, a charge of an amount according to the gradation level of the pixels from a current source connected to an end portion of the data lines **14**.

As described above, the charge supplied from the current source is distributed by the capacitance  $C_{dt}$  of the storage

capacitor **50** and the capacitance  $C_{pix}$  of the storage capacitor **132**. Since the capacitance  $C_{dt}$  of the storage capacitor **50** is sufficiently large in comparison with the capacitance  $C_{pix}$  of the storage capacitor **132**, the potential change amount of the gate node  $g$  is substantially determined according to the charge supplied from the power source and the capacitance  $C_{dt}$  of the storage capacitor **50**. Thus, since the relative variation of the capacitance  $C_{dt}$  of the storage capacitor **50** is small, it is possible to suppress the relative variation of the potential change amount of the gate node  $g$  in the writing period to be small. In this manner, it is possible to suppress the generation of luminance unevenness and to improve the display quality.

#### Arrangement of Potential Lines and Data Lines

In the above-described embodiments and modification examples, among the potential lines **16** and data lines **14** forming the storage capacitor **50** (that is, the potential lines **16** and data lines **14** which are adjacent to each other), the data lines **14** are electrically connected to a transistor **125** provided in one pixel circuit **110** out of two pixel circuits **110** which are adjacent to each other in the X direction (first direction), and the potential lines **16** are electrically connected to a transistor **122** provided in the other pixel circuit **110** out of the two pixel circuits **110**; however, the invention is not limited to such a form.

For example, as shown in FIG. **19**, the potential lines **16** and data lines **14** forming the storage capacitor **50** may be respectively electrically connected to the transistors **121** and **125** provided in the same pixel circuit **110**. In such a case, in the display unit **100**,  $(3n)$  potential lines **16** and  $(3n)$  data lines **14** may be provided so as to correspond one to one. Other

In such embodiments, an OLED which is a light-emitting element has been exemplified as an electro-optical element; however, for example, it may be one emitting light at a luminance according to the current such as an inorganic light-emitting diode or an LED (Light Emitting Diode).

#### Electronic Apparatus

Next, description will be given of an electronic apparatus applying the electro-optical device **10** according to such embodiments or application examples. The electro-optical device **10** is for high-definition display applications with small pixels. Thus, description will be given taking a head mounted display as an example of the electronic apparatus.

FIG. **20** is a diagram showing the external appearance of a head mounted display and FIG. **21** is a diagram showing the optical configuration thereof.

First, as shown in FIG. **20**, the head mounted display **300** includes temples **310**, a bridge **320**, and lenses **301L** and **301R**, which are similar to normal glasses in terms of the external appearance. In addition, as shown in FIG. **21**, in the head mounted display **300**, at the far side (bottom side in the drawing) of the lenses **301L** and **301R** which are in the vicinity of the bridge **320**, an electro-optical device **10L** for left eye use and an electro-optical device **10R** for right eye use are provided.

The image display surface of the electro-optical device **10L** is arranged to be on the left side in FIG. **21**. In this manner, the display image according to the electro-optical device **10L** is emitted in the direction of 9 o'clock in the drawing through the optical lens **302L**. A half mirror **303L** reflects the display image according to the electro-optical device **10L** in the 6 o'clock direction while allowing light incident from the 12 o'clock direction to pass therethrough.

The image display surface of the electro-optical device **10R** is arranged so as to be on the right side opposite to the electro-optical device **10L**. In this manner, the display image



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according to the electro-optical device 10R is emitted in the direction of 3 o'clock in the drawing through the optical lens 302R. A half mirror 303R reflects the display image according to the electro-optical device 10R in the 6 o'clock direction while allowing light incident from the 12 o'clock direction to pass therethrough.

In this configuration, the wearer of the head mounted display 300 can observe the display image according to the electro-optical devices 10L and 10R in a see-through state superimposed with the outside view.

Further, in the head mounted display 300, with parallax images for both eyes, when an image for the left eye is displayed on the electro-optical device 10L and an image for the right eye is displayed on the electro-optical device 10R, the wearer can be made to perceive the displayed image as though it had a sense of depth or a stereoscopic effect (3D display).

Here, in addition to the head mounted display 300, the electro-optical device 10 can also be applied to an electronic viewfinder of a video camera, a digital camera with interchangeable lenses, or the like.

What is claimed is:

1. An electro-optical device comprising:
    - a scanning line extending in a first direction;
    - a control signal line extending in the first direction;
    - a data line extending in a second direction;
    - a potential line extending in the second direction;
    - a first capacitor having one end electrically connected to the potential line; and
    - a pixel circuit corresponding to an intersection of the scanning line and the data line, the pixel circuit including:
      - a driving transistor having a first gate, a first source, and a first drain, the driving transistor being configured to control a current level according to a voltage between the first gate and the first source;
      - a writing transistor electrically connected between the first gate and the data line;
      - a storage capacitor having one end electrically connected to the first gate;
      - a light-emitting element configured to emit light at a luminance according to the current level during a light-emitting period; and
      - an initialization transistor configured to be on during an initialization period different from the light-emitting period, to control an electrical connection between the potential line and the light-emitting element, a gate of the initialization transistor being connected to the control signal line,
- wherein the light-emitting element does not emit light during the initialization period.

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2. The electro-optical device according to claim 1, wherein the light-emitting element contains an organic EL material.

3. The electro-optical device according to claim 2, wherein the light-emitting element contains an anode and a cathode.

4. The electro optical device according to claim 3, further comprising:

- a flexible printed circuit substrate; and
- an integrated circuit disposed on the flexible printed circuit substrate, the integrated circuit being configured to provide a data signal on the data line.

5. An electronic apparatus for display applications, the electronic apparatus comprising:

- the electro-optical device according to claim 4.

6. An electronic apparatus for display applications, the electronic apparatus comprising:

- the electro-optical device according to claim 3.

7. The electro optical device according to claim 2, further comprising:

- a flexible printed circuit substrate; and
- an integrated circuit disposed on the flexible printed circuit substrate, the integrated circuit being configured to provide a data signal on the data line.

8. An electronic apparatus for display applications, the electronic apparatus comprising:

- the electro-optical device according to claim 7.

9. An electronic apparatus for display applications, the electronic apparatus comprising:

- the electro-optical device according to claim 2.

10. The electro optical device according to claim 1, further comprising:

- a flexible printed circuit substrate; and
- an integrated circuit disposed on the flexible printed circuit substrate, the integrated circuit being configured to provide a data signal on the data line.

11. An electronic apparatus for display applications, the electronic apparatus comprising:

- the electro-optical device according to claim 10.

12. An electronic apparatus for display applications, the electronic apparatus comprising:

- the electro-optical device according to claim 1.

13. The electro-optical device according to claim 1, wherein a source or a drain of the initialization transistor is directly connected, without intervening transistors, to an electrode of the light emitting element.

14. The electro-optical device according to claim 1, further comprising:

- a power supply line extending in the first direction, wherein the driving transistor is configured to control an electrical connection between the power supply line and the light-emitting element.

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